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TECHNOLOGY REVIEW

SEPTEMBER 2002

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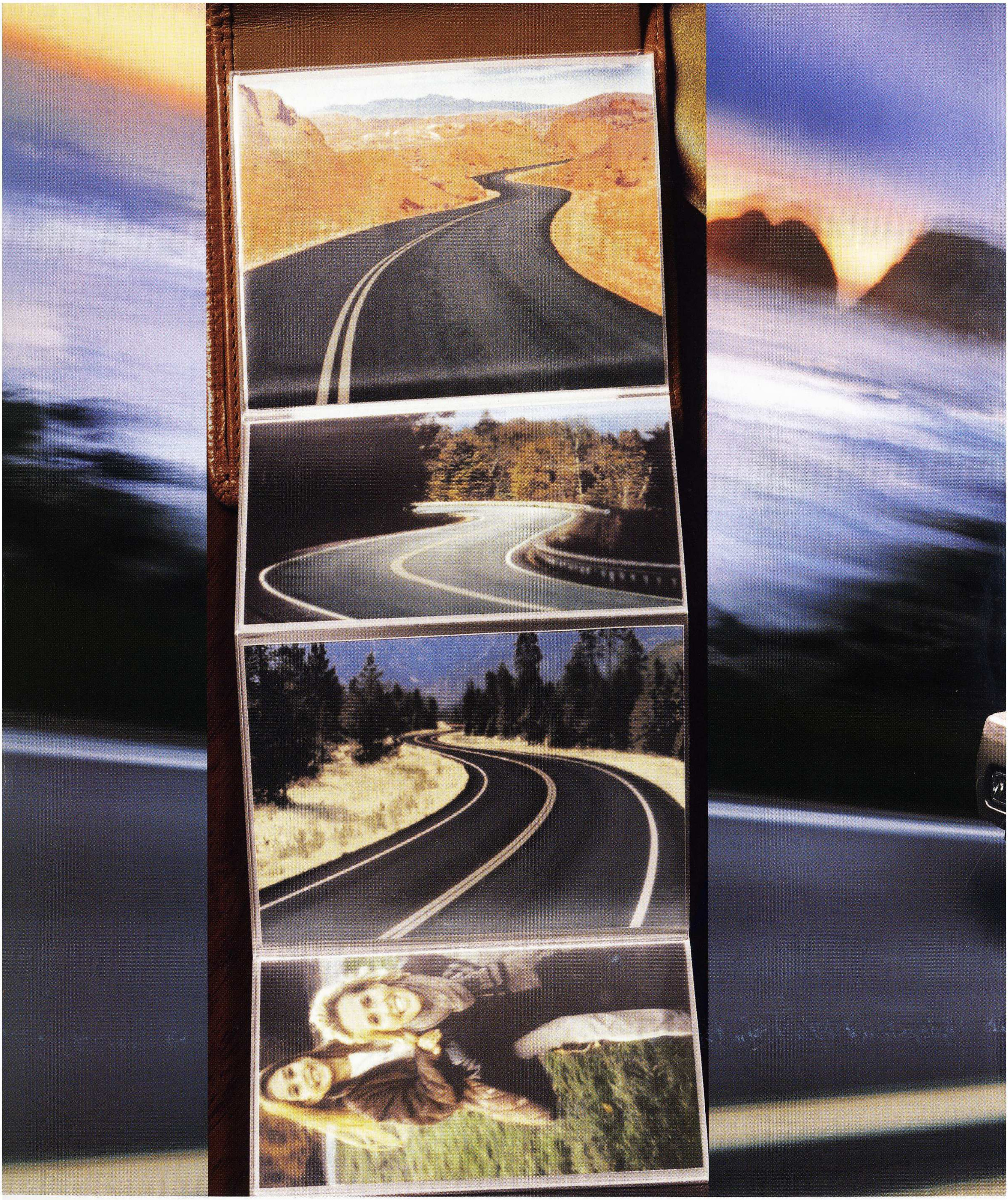

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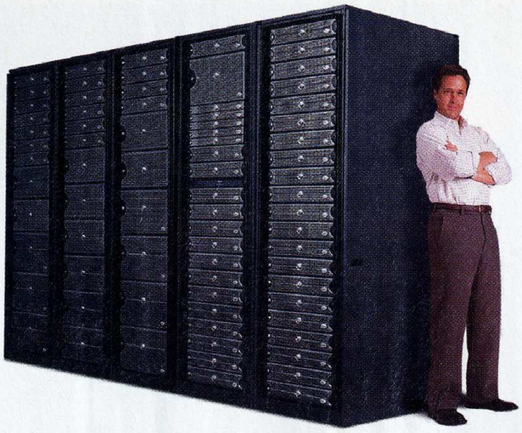

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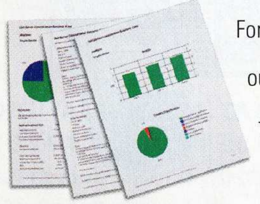

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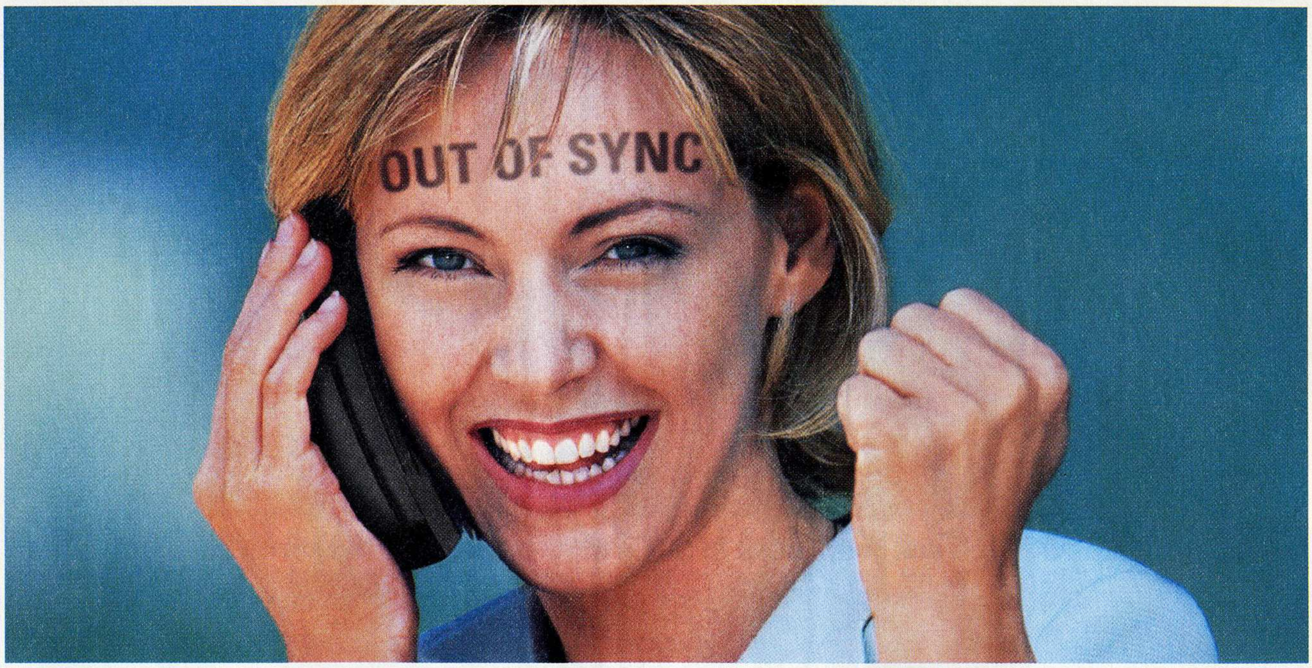

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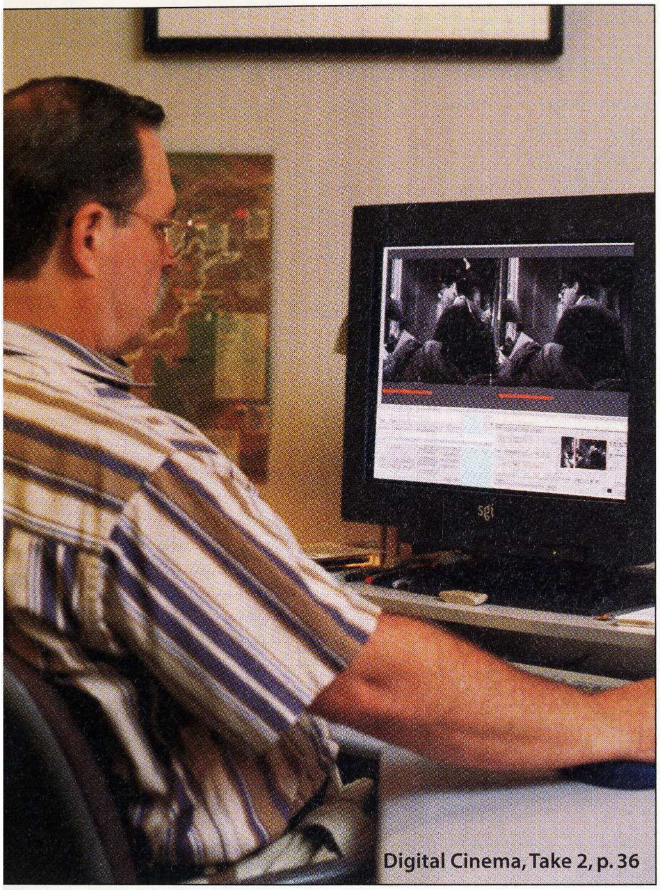

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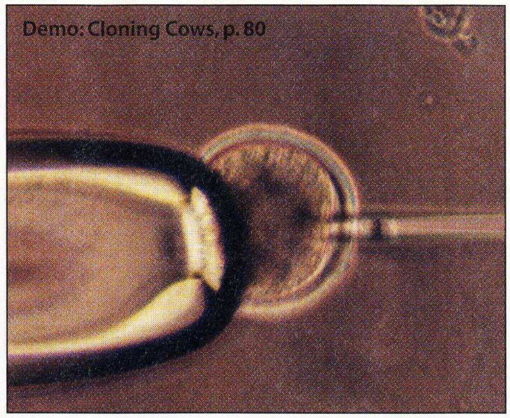

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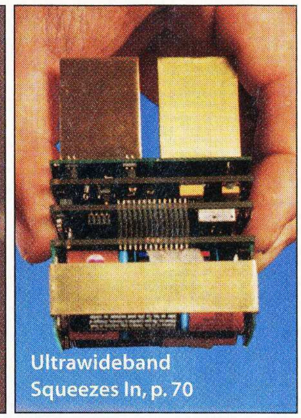

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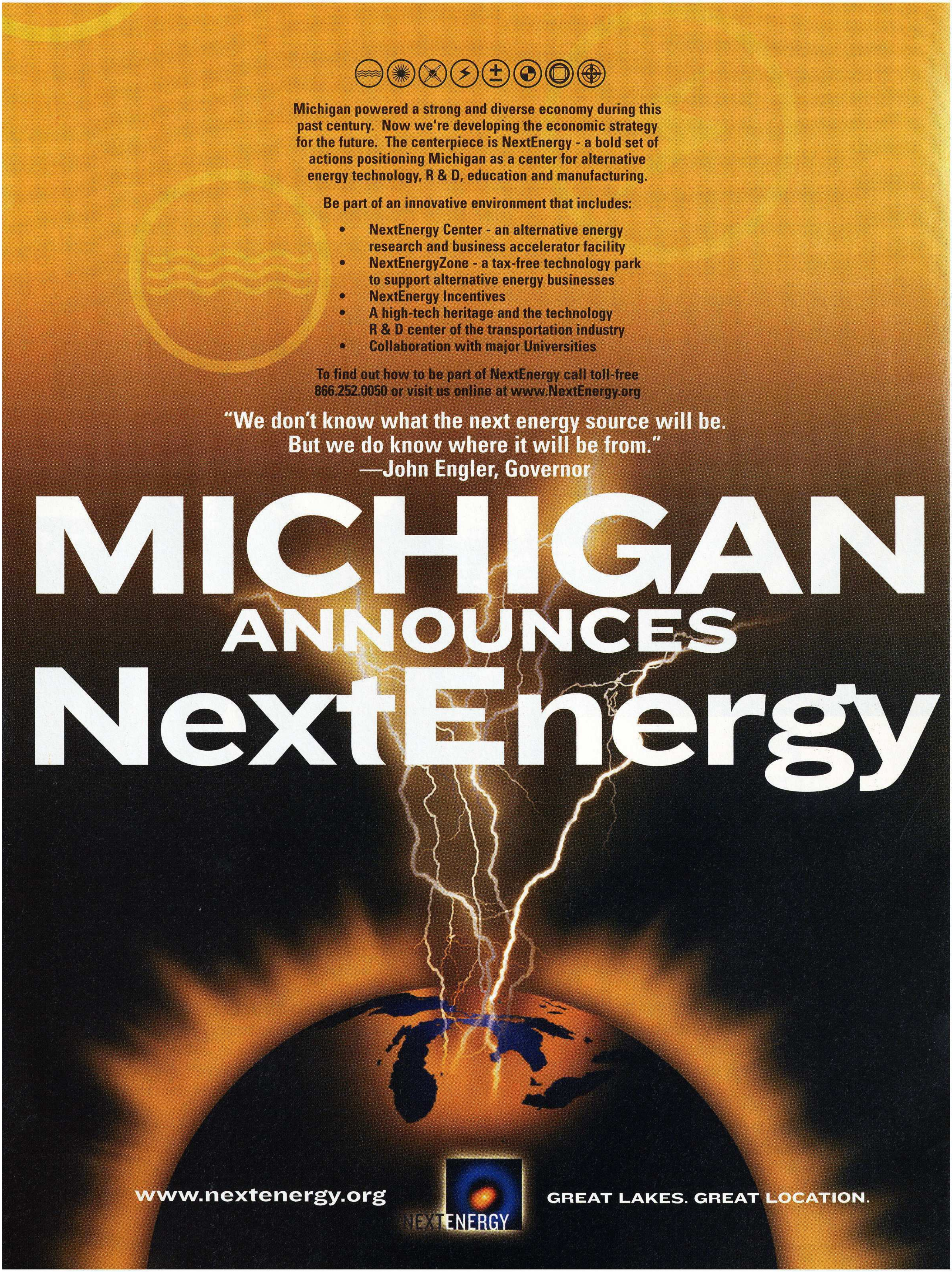

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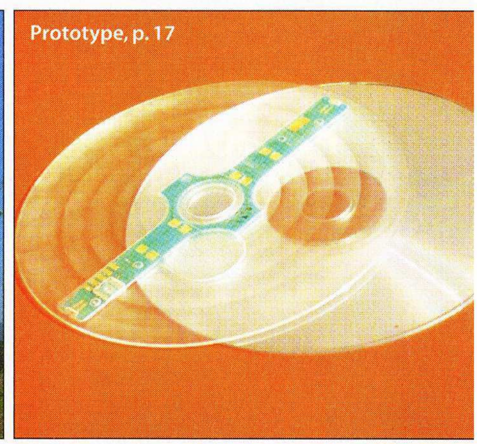

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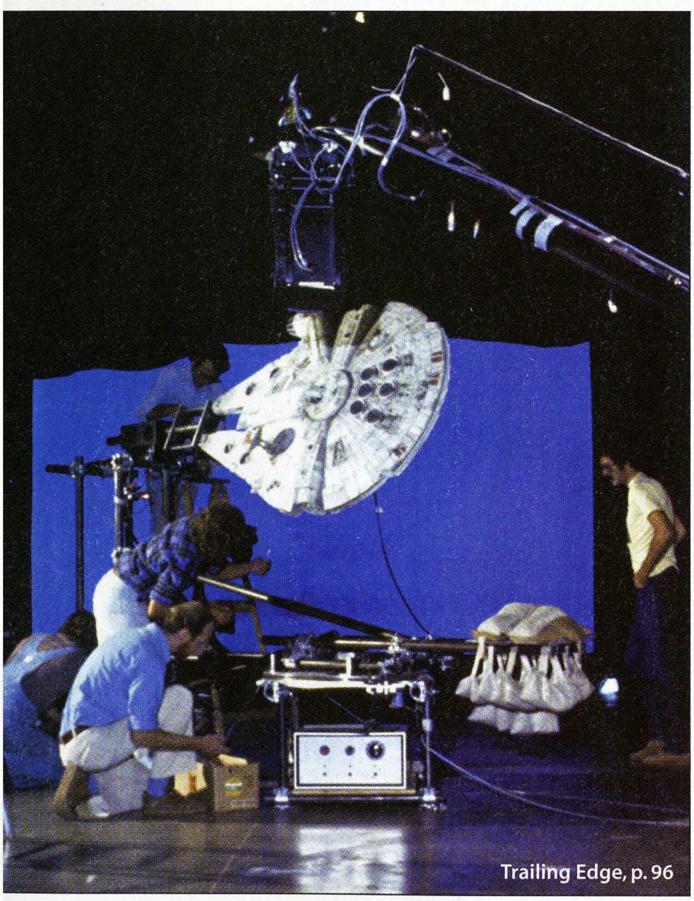

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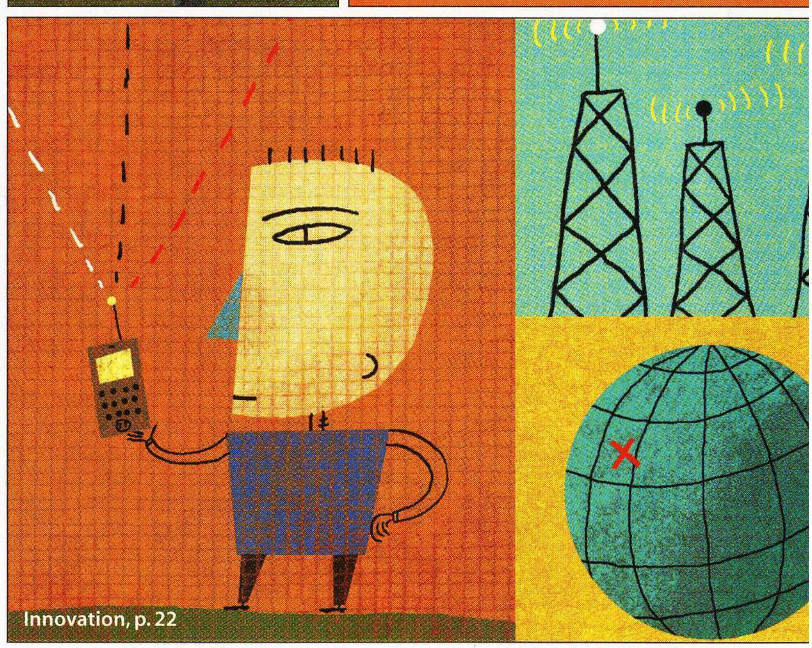

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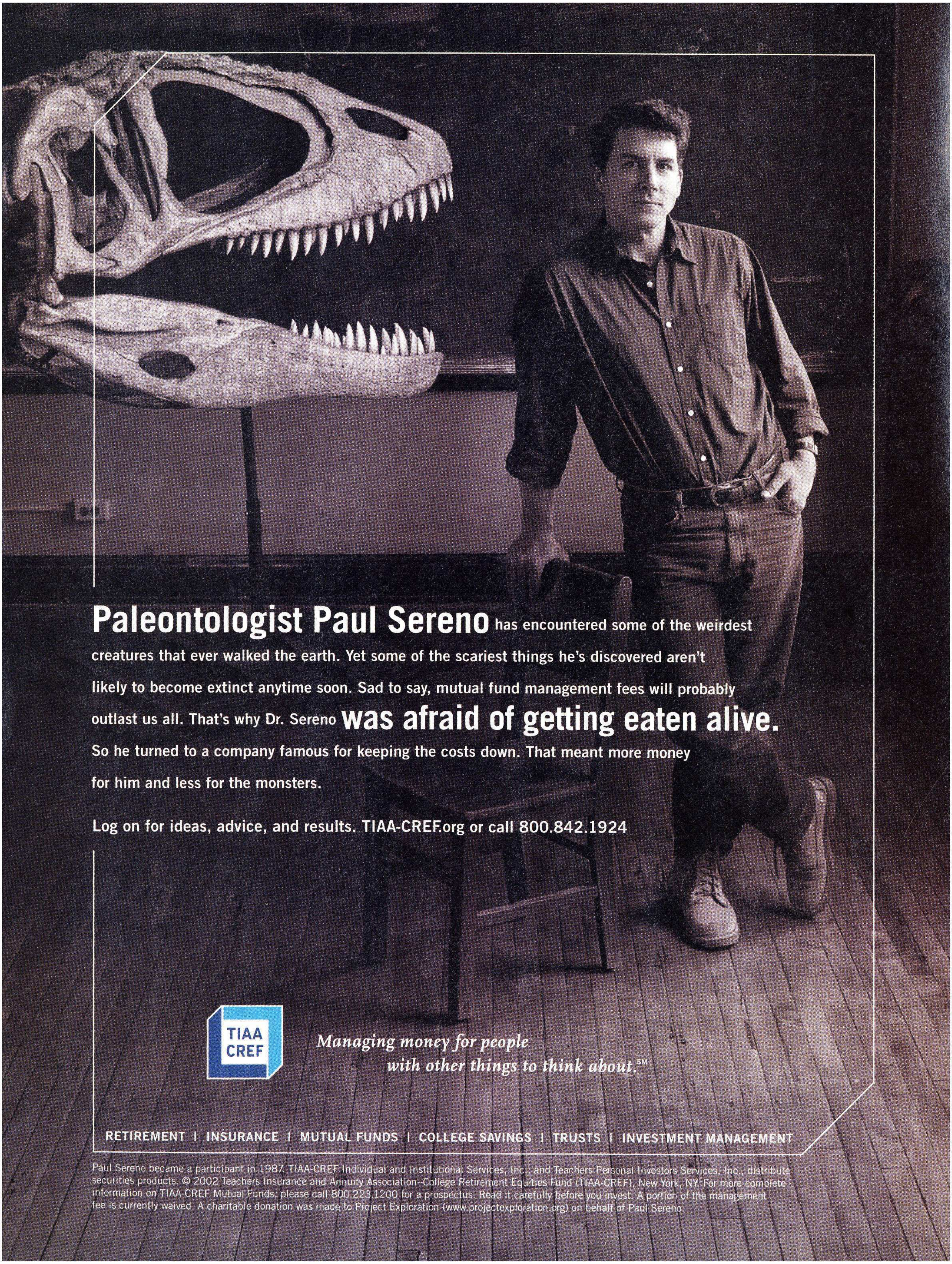

Paleontologist Paul Sereno has encountered some of the weirdest creatures that ever walked the earth. Yet some of the scariest things he's discovered aren't likely to become extinct anytime soon. Sad to say, mutual fund management fees will probably outlast us all. That's why Dr. Sereno was afraid of getting eaten alive.
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LEADING EDGE

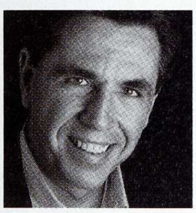
FROM THE EDITOR

JUNCTIONS

A great magazine, like a person dedicated to living a full and complete life, must continually evolve and improve. Now, as I take the helm of *Technology Review* from my friend and longtime colleague John Benditt, we here at the magazine are continuing the effort to better ourselves.

You won't see sudden, major changes. We think we're doing a lot of things right, and your letters and our reader surveys confirm that you like our strong focus on identifying emerging technologies, explaining how they work, and assessing their likely impact on business and personal life. I have written for the magazine since its relaunch more than four years ago and have served on staff as editor at large for the past two years. During that time, I have had a strong hand in shaping the magazine's stories and overall direction—and I believe firmly in staying the course. I'm fortunate to have working with me a talented and dedicated staff that also believes strongly in what we do.

This doesn't mean, however, that we can't get better. We are constantly looking to improve the writing, the subject matter and the impact of our stories—while also giving you a clear, digestible, intelligent, eye-pleasing and engaging view of what's just over the technological horizon.



WEBB CHAPPELL

One of the first changes I have made, one I think immediately improves the magazine, is in the area of engagement. Specifically, I am reinstating our letters page, formerly called "Feedback," now just "Letters." A leading magazine needs a forum dedicated to airing reader concerns, insights and criticisms—and a place to run corrections when necessary. Each month we will have room for only a few items. However, many more communiqués can be found in our Web forums, where postings have increased tenfold in recent months as we have restructured things to make it easier for readers to weigh in. And as the forums have taken off, so has the richness of the letters we receive.

One thing that is not going to change is our commitment to serving you a monthly diet of information and analysis unlike that which you'll find anywhere else. This month's feature lineup is Exhibit A. We have stories that cover everything from how to clone a cow to a versatile and controversial wireless technology called ultrawideband to a little-known but pivotal event in aviation. And one year after the horror of September 11, we present a chilling view of megaterror from esteemed physicist Richard Garwin, a longtime presidential science advisor.

But while these articles, and others in our pages, address important issues, I'd like to draw your attention to our cover story on the digitization of Hollywood, by Pulitzer Prize-winning *Los Angeles Times* reporter Michael Hiltzik. This piece gets at a vital point that goes far beyond the coolness factor of George Lucas shooting his latest Star Wars episode with digital cameras, and all the related talk of how bits and bytes are about to replace film. The truth, Hiltzik tells us from behind the scenes in moviedom, is that no matter how hard the computer whizzes have tried, digital technology falls short of film in some crucial ways—most notably in capturing lifelike clarity, color and contrast. So instead of digital cameras and computers outmoding film, what is evolving is an industry where directors, camera operators and postproduction technicians must master two media—celluloid and electronic—and extract the best from both in order to evolve their art.

The same general lesson holds true for many technological revolutions: while technology can bring true transformation, it does not necessarily replace one way of doing things with another. So the next time you hear about a revolution that is going to do away with an industry, look closely. Something special may be happening at the junction of old and new. —*Robert Buderi*

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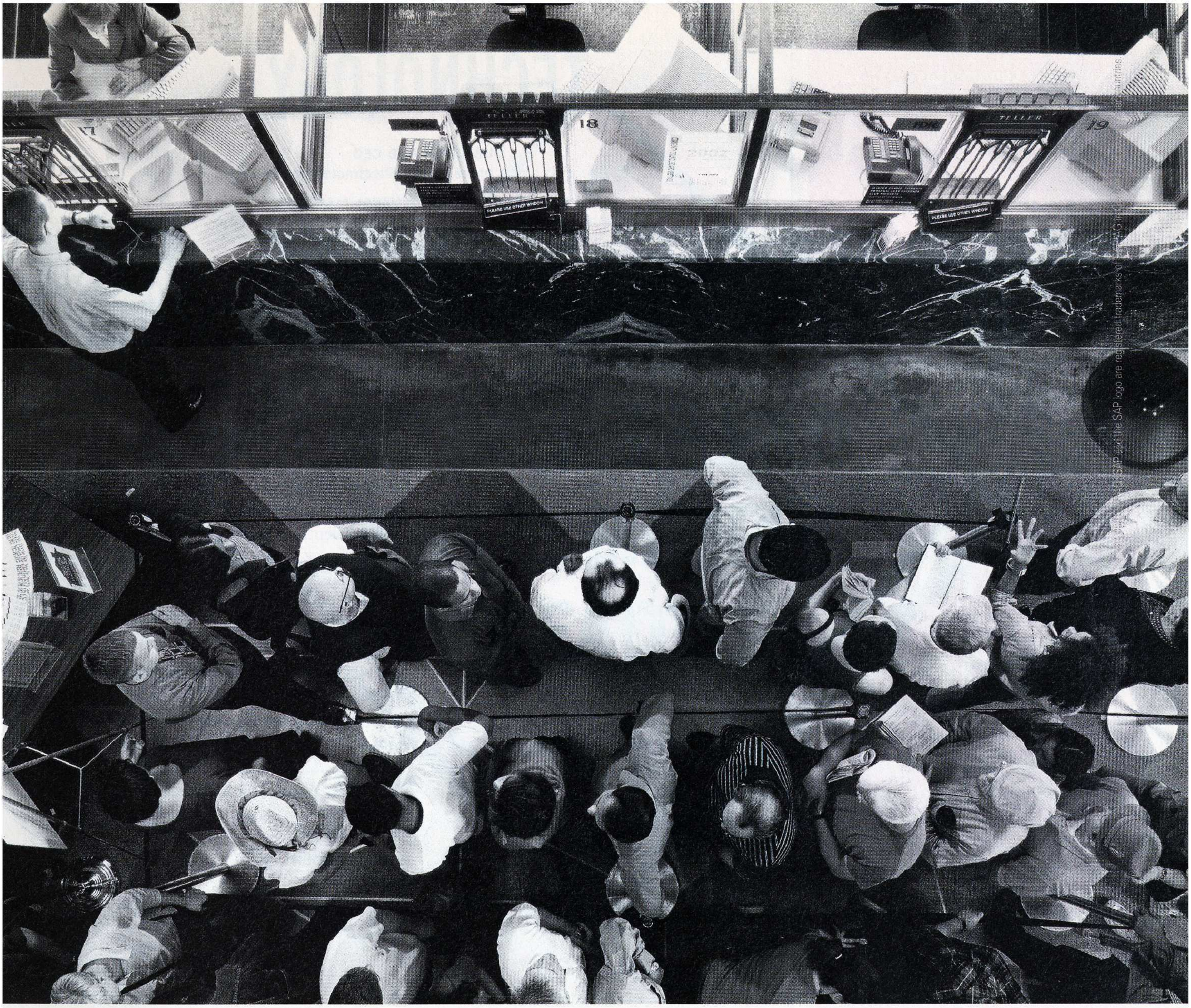

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GOVERNMENT SHOTS

It is certainly tempting to believe that if the U.S. government throws enough money and control at production, the problem of stocking vaccines will go away ("Should the Government Make Vaccines?" *TR* May 2002). But that simply isn't the case. Viruses and bacteria will behave no more predictably for the government than for industry. The good news is that there are plenty of things that the government can do to shore up the system. It can look to a rational stockpile program. It can direct adequate funding to the Food and Drug Administration so that its own labs and training remain state of the art.

The implication that the private sector is unwilling to work with government to produce limited-use vaccines is simply untrue. Industry is the greatest repository of expertise on how to bring vaccines to licensure, an expertise that should be put to use for the national good. To achieve that goal, we need well-designed business proposals with clear statements of quantities, and requirements that reflect the realities and complexities of vaccine research and development as well as manufacturing costs.

The immunization partnership between private and public sectors has resulted in the effective control of vaccine-preventable infectious diseases in this country. We should build on the success of that paradigm rather than destroy it.

David J. Williams
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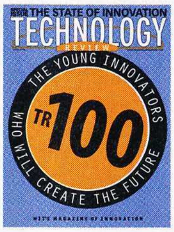

"Industry is the greatest repository of expertise on how to bring vaccines to licensure, an expertise that should be put to use for the national good."

CUSTOMER CONCEPTS

Michael Schrage is his usual engaging self in his June column ("Mimetic Management"). But I believe that knowing who your customer wants to be is the sine qua non of relationship-building and requires a deep, continuous connection. That is the real value question, and it's not necessarily related to imitation.

Also, decision-makers (read "innovators") first attempt to solve problems from the seat of their pants and then seek the advice and recommendations of trusted peers. Only when this subjective approach fails do they lapse into analytic activities. It is the cheapest approach in terms of buying information about customers. In this age of rapid change, role models and competi-

tors may provide the only information that managers can afford!

David M. Sherr
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BORDER CONTROL

Whatever valid points there may be in Simson Garfinkel's column concerning Internet security ("Leaky Cyber Borders," *TR* June 2002) are drowned out by unnecessary American condescension. Does the author really believe that spam or viruses originate only in shadowy corners of the world?

How would American business react if Europe, for example, decided to monitor commercial traffic coming from the United States in order to "protect itself"? The desire to erect electronic "borders" is a throwback to an outdated view of the world. Internet security is a global issue and should be addressed in an inclusive manner.

Fergus Cassidy
Dublin, Ireland

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Wade Roush's recent article ("Digital Pirates Beware," *TR* June 2002) should not be read lightly. A "patriot" does not have to be a conspiracy theory buff to be suspicious of the recent announcements by attorney general John Ashcroft. Are increased FBI powers regarding the Internet more for Big Business seeking copyright enforcement or for terrorism prevention?

There is no doubt that the big money today is with intellectual property. Unfortunately, the true authors of intellectual work rarely receive their fair share; however, they often receive federal funding. In such cases, we, the consumers, end up paying on both ends—and now we may be paying big bucks for enforcement, too.

Rick Happ
New Bern, NC

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Correction:

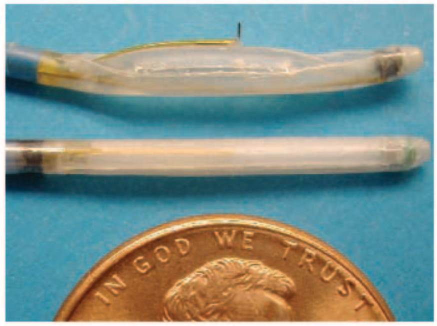
The profile of TR100 finalist Eric Bonabeau (*TR* June 2002) cited his ant-based, "swarm intelligence" algorithms as the technology used by Southwest Airlines to revise work procedures and baggage flow for the company's cargo-handling applications.

Algorithms of the same general type—employing a technique known as agent-based modeling—were used by Bonabeau's former employer, the Bios Group, to help the airline improve the efficiency of these operations. However, neither Bonabeau nor his ant-based algorithms were involved in the implementation of the airline project.

PROTOTYPE

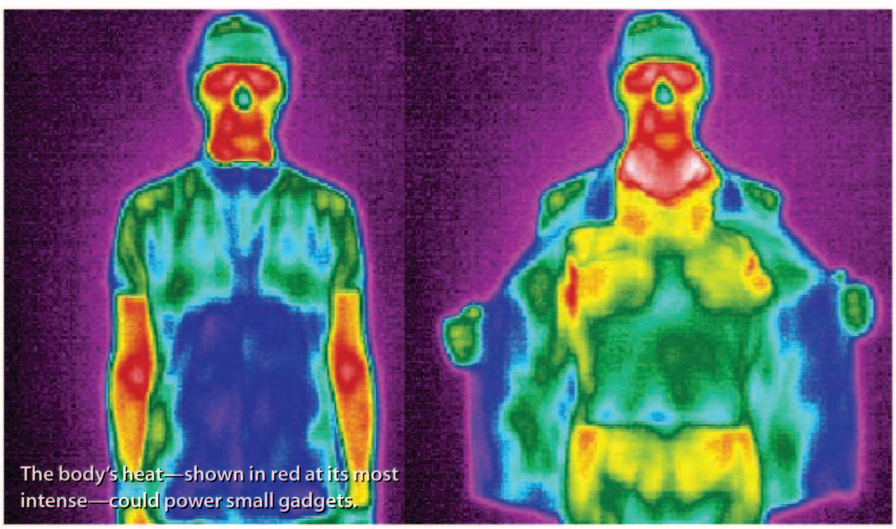
STRAIGHT FROM THE LAB: TECHNOLOGY'S FIRST DRAFT

BLOOD SHOT



Hydraulics extend (top) and retract a tiny steel needle in EndoBionics' artery-injecting device.

Useful, but barbaric. That's how San Leandro, CA-based EndoBionics' CEO Lynn Barr describes balloon angioplasty—the use of a balloon-tipped catheter to open clogged arteries. The procedure itself causes artery-narrowing scarring in about 20 percent of the roughly 600,000 people in the U.S. who undergo it each year. To stop this scarring, mechanical engineer and EndoBionics founder Kirk Seward created a retractable polymer sheath for a steel needle one millimeter long and roughly the diameter of two hairs. After an angioplasty, a surgeon could guide the sheathed needle through an artery in the patient's leg or neck to the coronary artery. Once the device was in place, a microscale hydraulic system would allow the surgeon to retract the sheath while simultaneously pushing the needle into the artery wall. This way, the device could inject a tiny amount of a blockage-preventing drug directly into the site where scarring and blockage could occur. The technique would deliver the drug much further into the artery walls than other methods being developed for this purpose, Barr says. EndoBionics plans to partner with a yet unnamed medical device company to bring the technology to market in late 2004. Eventually, Barr says, the microneedle could be used to deliver tumor-killing drugs or genes to the brain.



The body's heat—shown in red at its most intense—could power small gadgets.

BODY POWER

Our bodies ooze energy in the form of heat. Infineon Technologies, a microelectronics company in Munich, Germany, has developed a dime-sized chip that converts this heat into enough electricity to power a small electronic gadget, which would otherwise rely on tiny and expensive batteries. One side of the "thermogenerator" faces the body, and the other faces the air; the temperature difference between the two sides produces a current. Unlike other heat-to-electricity devices, which are made out of expensive and toxic metals, Infineon's chips are silicon—a cheaper and more benign material.

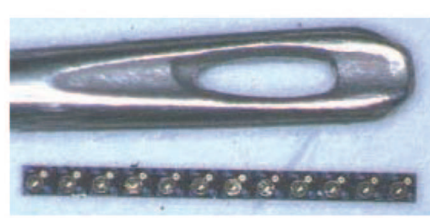
Given a typical temperature difference at the wrist of 5 °C, prototype devices can generate enough power for a wristwatch—around one microwatt per square centimeter—says Werner Weber, head of Infineon's Laboratory for Emerging Technologies. Infineon is working with a watchmaker to incorporate the thermogenerator into the firm's products. The chips, says Weber, could find their way onto the market in two years in watches or wearable medical devices; a thermogenerator embedded in a jogging suit, for instance, could power a heart sensor.

ROTO ROCKETTE

The MIT Rocket Team is pioneering "the first new idea in a rocket engine that I've heard of in decades," says Edward Crawley, head of the MIT Aerospace Department. Team leader Carl Dietrich has patented a device replacing the turbines that, in a conventional rocket, run the pump that pressurizes the fuel and liquid oxygen. Dietrich instead uses something akin to a lawn sprinkler with spinning jets. This modification could allow a rocket to operate efficiently even when scaled down to the size of a can of paint. Shrinking a conventional rocket engine to that scale results in excessive leakage around the turbine blades, spoiling performance. The team expects its test rocket to create 90 to 180 kilograms of thrust, enough to launch a small video observation system, at a cost of a few thousand dollars. If testing of the fourth prototype proves successful, the rocket could take its maiden voyage in about two years.

LITTLE SCREEN, BIG PICTURE

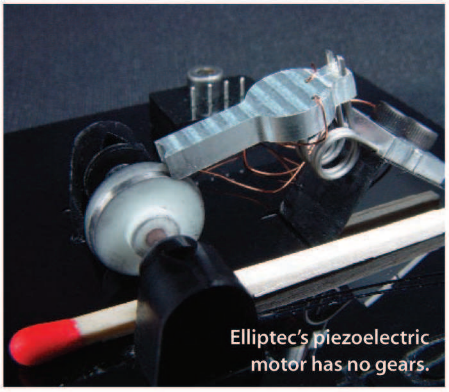
Cell phones and personal digital assistants get smaller each year, but greater portability comes at a price. The devices' shrunken screens make information hard to read—and even harder to share with others. V. Michael Bove Jr. and Wilfrido Sierra at MIT's Media Lab are developing a miniature laser projector to make handheld devices easier on the eyes. The projector consists of an array of semiconductor lasers spaced micrometers apart, approximately one laser per pixel. A tiny mirror mounted above the array rotates to sweep the beams up and down while their intensities are varied, reproducing text and simple images. With the touch of a button, a cell phone could project its postage-stamp-sized display as an image up to a meter diagonal on a conference room wall. The compact, low-power lasers won't take up much room and won't squander battery life. Bove expects the projectors to appear in phones in two to five years.



Tiny lasers will turn handhelds into projectors.

COURTESY OF HONEYWELL VCSEL OPTICAL PRODUCTS (LITTLE SCREEN); COURTESY OF INFINEON TECHNOLOGIES (BODY POWER); COURTESY OF ENDOBIONICS (BLOOD SHOT)

GOOD, CHEAP VIBRATIONS



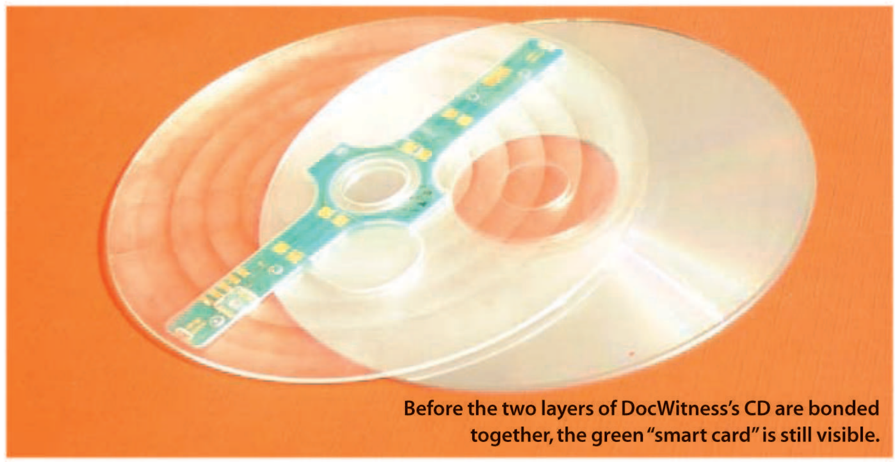
Elliptec's piezoelectric motor has no gears.

Today's small electric motors—common in electronics from toys to CD-ROM drives—are complex, noisy and inaccurate at slow speeds. Elliptec, a Dortmund, Germany, spinoff from Siemens, has developed a simple and inexpensive piezoelectric motor, which uses the electrically induced vibration of special ceramic materials to spin a wheel or move a rod. Earlier piezoelectric motors cost hundreds of dollars; Elliptec's gadgets may reach market at $1 each, thanks to new materials and a simpler three-part design that makes them easy to manufacture. The penny-sized gadget is quiet, one-twelfth the weight of a traditional electromagnetic motor, needs no gearbox and can generate a wide range of exact speeds, according to Elliptec president Bjoern Magnussen. Its first application is likely to be in robotic dolls and toys that could use several such motors to produce realistic eye and mouth movements. Magnussen says the company began shipping prototypes to toymakers and other electronics companies earlier this year.

ISLAND-HOPPING DATA

Telecommunications networks are like the highway system—an amalgam of six-lane freeways and winding country roads. Most networks try to send data over the freeways, but that can lead to massive congestion. Software developed at the Swiss Federal Institute of Technology in Lausanne looks at traffic across the entire network, calculating more efficient routes in real time. Lab simulations suggest that the software, which would run at a central switching facility, could increase a network's capacity by as much as 40 percent.

The software divides a network into "islands," each separated from its neighbors by particularly sluggish data connections—that is, potential bottlenecks. The islands are subdivided into smaller islands, separated by slightly faster connections, and so on. As traffic along a given route increases, the available bandwidth decreases, so the islands are continually grouped and regrouped; but the software always plots the route with the highest bandwidth. "The search turns out to be quite efficient," says lead developer Boi Faltings. He is looking for industry partners to test the software.



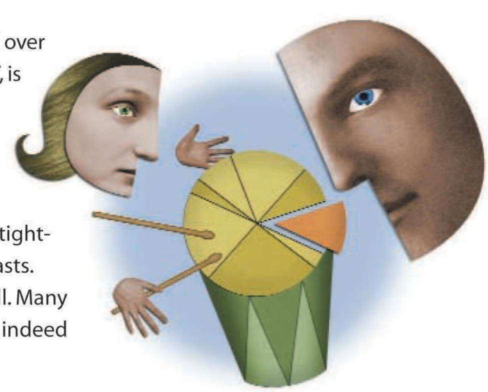
Before the two layers of DocWitness's CD are bonded together, the green "smart card" is still visible.

CD COPY STOPPER

Software pirates beware: CD-ROMs might soon be armed with invisible security systems that keep their contents—games and business applications—under lock and key. The OpSecure CD was developed by Rosh-Ha-ayin, Israel-based Doc-Witness. A "smart card" embedded in the CD unlocks the disc's encrypted content. You can copy the CD, but without the card the software won't run. Try to install the software on more computers than the publisher allows and the smart card will shut you down. The technology works by turning an ordinary CD drive into a smart-card reader. A photodetector at the edge of the CD turns the drive's laser light into electrical pulses, which travel to the embedded smart card and request the key. If the card deems the request legitimate, it returns the key as an electronic signal that an onboard light-emitting diode converts into light and beams back to the drive. Doc-Witness is negotiating with several business software publishers and aims to begin manufacturing the secure CDs in January 2003. The company is also working on a similar security system for DVDs.

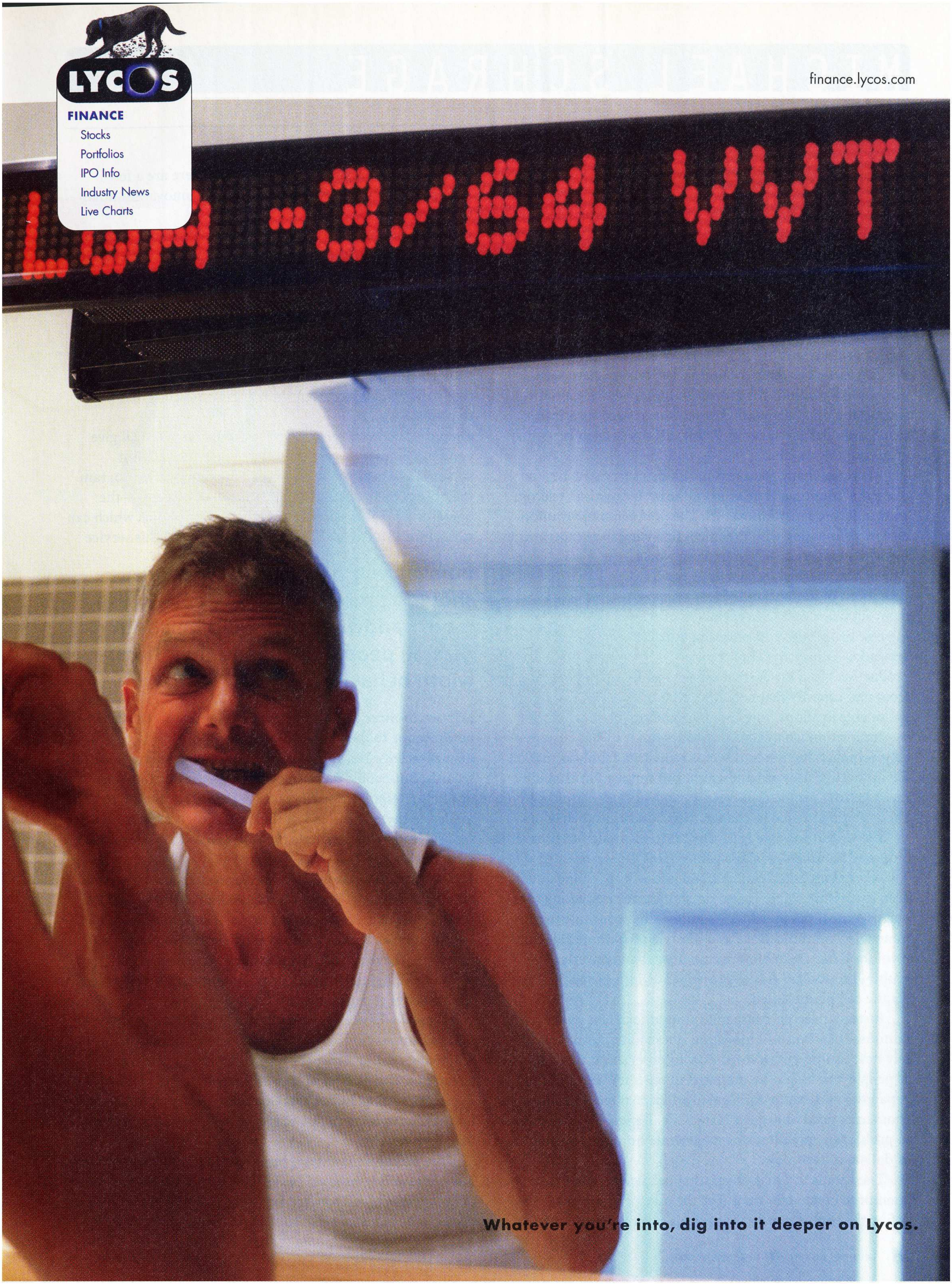
RADIO RELIEF?

For webcasters, making sure that musicians receive royalties when their songs are played over the Internet is a tedious, paperwork-intensive business. Now Websound of Brattleboro, VT, is touting software that automatically sifts through Web server logs to distinguish songs from graphics and other files transmitted to Web surfers. The software matches the file names with song-specific information—artist, recording label and so forth—from Internet music databases and submits a weekly report on behalf of the webcaster.



The technology, called Radlog, comes just in time to help webcasters comply with tightened U.S. Copyright Office rules governing how musicians are paid for Internet broadcasts. Websound says it plans to license Radlog for as little as $100 per month starting this fall. Many webcasters had said that the reporting required by the new rules would be "expensive, indeed impossible," says Jeff Daniel, Websound's CEO. "Well, we've figured out a way."

JOYCE HESSELBERTH (ILLUSTRATION); COURTESY OF DOC-WITNESS (CD COPY); COURTESY OF ELLIPTEC (VIBRATIONS)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PUSH-BUTTON INNOVATION

Hello? *Hello?* Can you hear me now? The telecom sector seems badly disconnected. Analysis reports state that over two trillion dollars' worth of its market value has evaporated in less than 30 months. The high-flying, high-tech visionaries of the high-bandwidth future—Global Crossing, Covad, Williams, XO, Teligent, et al—have vanished into bankruptcy or liquidation. The AT&Ts, WorldComs, Qwests and Sprints, as well as their counterparts overseas, have seen their bold ambitions for growth in billion-dollar gambits such as the third-generation wireless standard turn into mad scrambles for survival. A few dishonest telco execs may even be going to jail.

There are many good reasons for this sorry state beyond corrupt accounting. Here's one of the best: America's telecom companies are lousy innovators. They've been more comfortable experimenting with their debt financing than experimenting with new service offerings. Even worse, they appear married to hopelessly outdated definitions of innovation. Telecom equipment suppliers do a sensational job of creating new bandwidth and extending physical networks—sensational, but counterproductive, given the current capacity glut. Does new capacity that nobody is willing to use or able to afford truly count as innovative?

Innovation isn't what companies do; it's what customers adopt. In fact, the telecom sector remains a fabulous market for innovative uses of bandwidth. But innovation shouldn't mean getting people to use *more* bandwidth; it should be about getting people to change their bandwidth behaviors.

Clever features like NTT DoCoMo's i-mode Internet services and handheld wireless games *(see "The Wireless Arcade,* TR *July/August 2002)* can be tremendously appealing and even successful. There is also no shortage of marketing campaigns—most notably AT&T's mlife—that continue to promote telecommunications as a lifestyle revolution. But this revolution has created more casualties than converts. The multibillion-dollar bids to create bandwidth-based lifestyles via the cell phone failed.

Instead, telecom companies should focus on pushing buttons. Push-button innovation doesn't ask customers to buy new equipment or learn how to program; it treats them as people who might be prepared to tap a few extra keys to get a little extra value for a small additional fee. Telephone companies need only get a certain small percentage of callers to push a few more buttons to generate hundreds of millions of dollars in cash flow.

The idea is to build on existing behaviors rather than attempt to create new ones. For the sake of argument, let's define the problem as how to get an extra $120 a year from you, the high-margin cellular customer. Here are a few examples of what profitable push-button innovation might look like:

- **Transcription/recording:** Many professionals would cheerfully pay a premium for a transcript of conversations with clients and customers—local laws permitting, of course. Why not a push-button sequence that triggers a recording of the conversation? The recording would then be run through any of the rapidly improving voice recognition transcription programs on the market, time-stamped and e-mailed to the subscriber. How many conversations do you have in a week that you'd like to have transcribed? How much is that worth to you?
- **Improved operator services:** Every cellular service will give you phone numbers and offer to connect the call. But sometimes you also want to record the number. Reprogram the 411 service so that—for an extra 35 or 40 cents—the operator sends the number directly to your phone, which can store it for future use. Each customer that used this service just two or three times a week could generate $50 a year in new revenue to the phone company.

Innovation in the telecom sector shouldn't mean getting people to use more bandwidth; it should be about getting people to change their bandwidth behaviors.

- **E-mail records:** Yes, you can go online now to survey your call records. But people on business trips might welcome the option to designate which records of which calls they want e-mailed to them at the end of the day for their expense reports. Tap #1 to designate that this is a call for which you want a receipt.
- **Teletificates:** Bookstores, clothing stores and record stores all offer gift certificates. Phone companies should provide a toll-free number that people can call to buy "teletificates" worth a certain number of calling minutes for friends or family members. The teletificate is automatically credited to the account of the recipient, who gets a voice mail or e-mail telling him or her of your generosity.

What do these ideas have in common? They all lend themselves to automation and require only marginal investments in modifying existing networks. More importantly, they are all engineered around convenience and ease of use as opposed to paradigm busting. In fact, it is easy to imagine people paying for these services precisely because of their familiarity rather than their novelty.

The telecommunications business has every incentive to get more innovative. It should be deluging its customers with offers of new products and services. For some reason that's not happening. The industry needs to start pushing their buttons. TR

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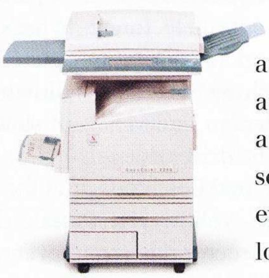

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THE NETWORKED CAR

The key to superefficient automotive systems: software

A few mysterious cars grace the parking lot of the Bosch test track, about 100 kilometers northeast of Stuttgart, Germany. Most are next year's body styles, fenders shielded by foam panels and tape to thwart nosy competitors or journalists. But perhaps the most radical prototype is the most outwardly prosaic: a midnight blue Audi station wagon. Closer inspection reveals computers stuffed into its trunk, a joystick grafted onto its center console, a video camera glued to the windshield and a radar antenna bulging from a hole sawed in the front grill.

The digital auto provides a glimpse into a future where vehicle systems like brakes and transmission are electronic, software-controlled and, above all, networked with each other and with the outside world. "To put it very simply, you are turning the car into a computer," says Rainer Kallenbach, general manager of the group that modified the prototype for Bosch, a major auto industry supplier based in Stuttgart. By contrast, the systems in today's cars "have limited communication and are not jointly operated," which also limits their efficiency, Kallenbach says.

Bosch's so-called Cartronic software can fine-tune braking and downshifting, optimize engine temperature and manage the generation and consumption of electricity. The company plans to bring the technology to market as early as 2005, and its work is expected to lead, eventually, to safer, peppier, 30-kilometers-per-liter (80-miles-per-gallon) cars that still use internal-combustion engines yet emit little more than carbon dioxide and water.

The continually decreasing cost of the underlying microprocessors and other components—combined with competition among automakers and major auto suppliers—means automotive systems like Bosch's will roll steadily into the marketplace over the next decade, starting with high-end models, according to Lino Guzzella, codirector of the Measurement and Control Lab at the Swiss Federal Institute of Technology in Zürich, which tests and develops engine control systems. "This is where the future is for everybody in this business," Guzzella says. "Fuel consumption can still be cut in half, and emissions can be zero."

Bosch's concept car doesn't go quite that far, but it does begin to rethink some of a car's most basic operations. The brake and transmission controls are electronic rather than mechanical. The joystick isn't meant to suggest that driving tomorrow's cars will be like playing video games; rather, Bosch wanted a tangible demonstration of how multiple systems can be controlled in concert, by software. Move the joystick forward, and the car drives forward, as the trunk-bound PCs continually choose the optimum engine speed and transmission gear. Move it back, and a third element, the brakes, is also activated. The software saves three to five percent in fuel consumption over traditional operation via the gas pedal, brake pedal and gearshift, Kallenbach says.

A new software program means the same joystick provides Porsche-like acceleration and braking. Like the settings on your PC, the car's parameters can be infinitely tuned. What's more, video and radar inputs can tell of an approaching obstacle, allowing the computers to intervene and slow down before the driver does.

A second Bosch vehicle at the track, a modified Volkswagen Passat, demonstrates the networking concept at a deeper level, with one basic system: engine cooling. To prevent blown hoses or a warped engine block, today's standard mechanical valves and belt-controlled water pumps keep a car's engine in the 90 °C to 95 °C range. The rudimentary controls err on the safe side, keeping the engine protected but somewhat too cool for optimal fuel efficiency. But in the modified Passat, software-controlled valve actuators and an electric pump allow precise temperature control, setting the engine at 115 °C at cruising speed or 90 °C during hard acceleration or steep climbing, as reported by sensors elsewhere in the network. This thermal-management system can improve fuel economy by another two to five percent, says Kallenbach. And it can call the shots within the broader network, too. For example, when the engine is cold at ignition, the system could tell the transmission to use a lower gear, warming up the engine faster; a warm engine not only

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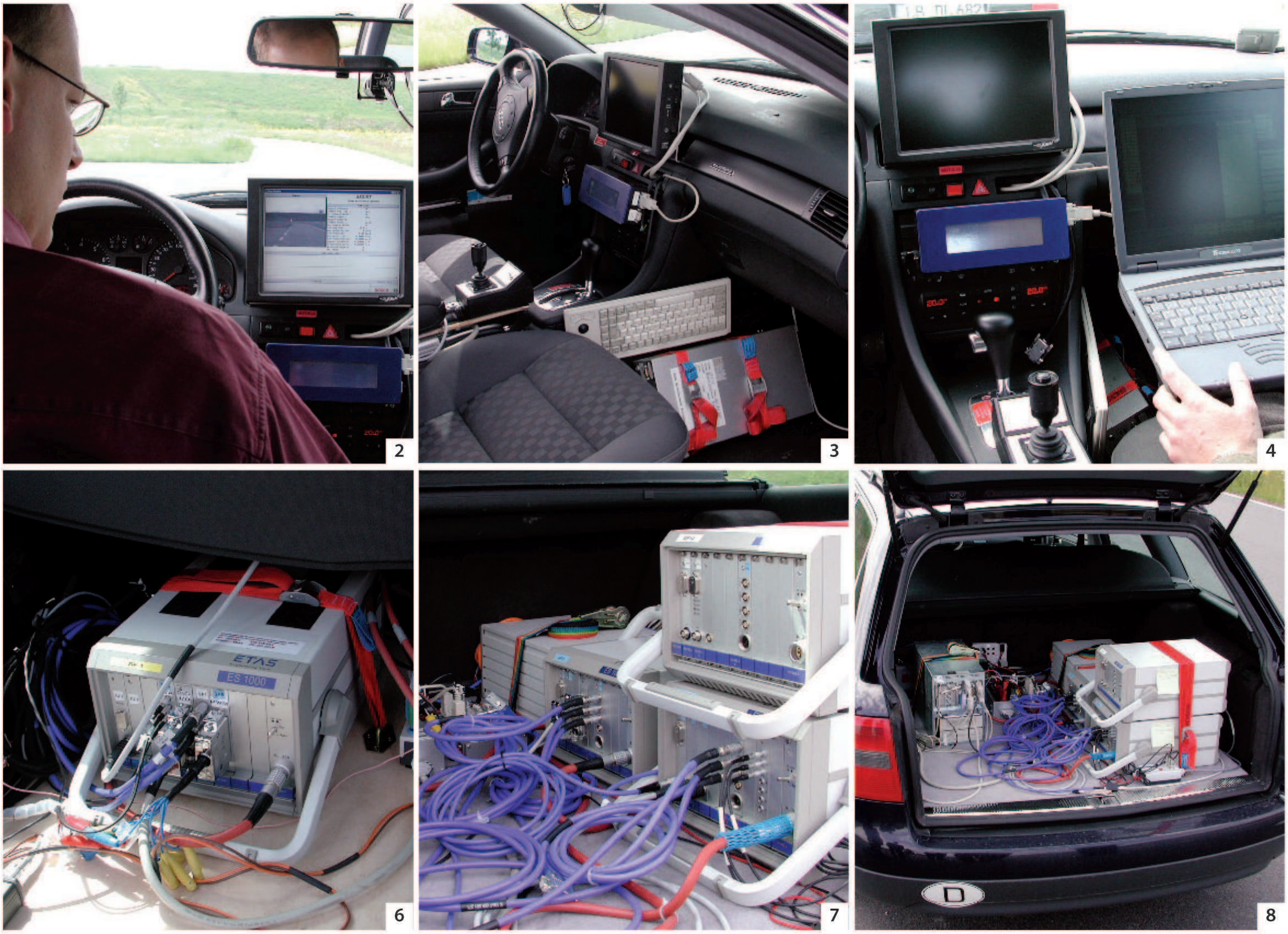


Bosch's modified Audi hits the test track (1). Front-seat displays track software settings (2-4). A joystick replaces the gas and brake pedals (5), and PCs in the trunk control the engine, transmission and brakes (6-8).

COURTESY OF BOSCH (1, 2); DAVID TALBOT (3-8)

saves gas but emits less pollution and suffers less wear.

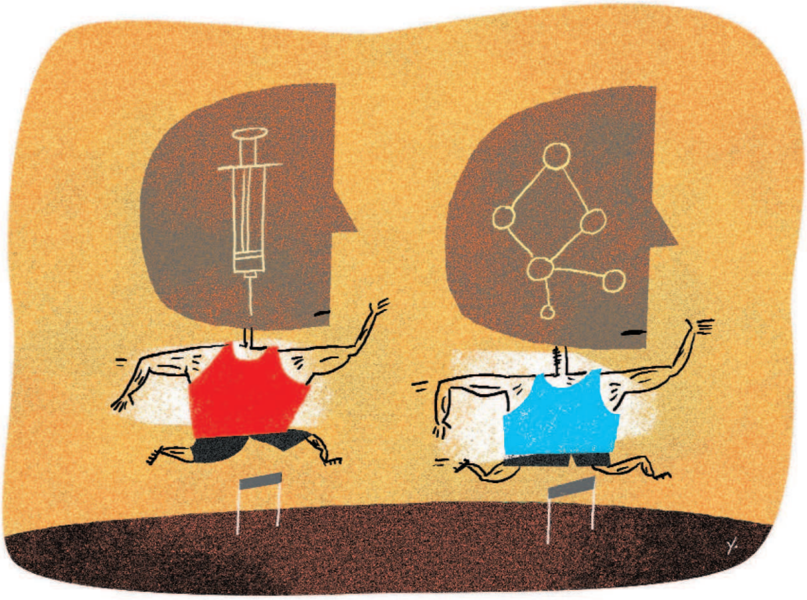
The same software principles extend to systems like air conditioning and could be used to manage steering—though that's farther off due to the added risks that switching from mechanical to electronic controls would bring. Big jumps in fuel savings will come as more and more cars include "idle stop" functions (shutting down the engine at stoplights) and regenerative braking, in which braking force that would normally dissipate as friction-generated heat is captured to produce electricity.

Other experimental functions in Bosch's digital car improve safety rather than efficiency. Its video and radar systems sense oncoming traffic and warn the driver if a collision is imminent, decelerate the car automatically, and could even intervene with future electronic steering systems.

Bosch, which invented the now ubiquitous antilock braking system, "is a leader in applying new electrical technologies to automobiles," says Thomas Keim, an electrical engineer at MIT. "Eventually, everybody is going to have systems that work like this."

But making these software visions a reality won't be easy. To keep drivers safe, coordination software will need a backup—either a second, redundant system, or one that monitors the performance of the main software. Software controls must be cheap to build and install, standardized for many car models and simple to upgrade. They must also be far more reliable than typical desktop software—or as the industry takes steps toward greater software control and system integration, the phrase "car crash" will take on a maddening new meaning.

Despite the challenges, however, the era of the digital car is approaching too fast to stop. —*David Talbot*



DETERRING GENE DOPING

Officials try to head off abuse by athletes

BIOTECHNOLOGY | In the race between elite athletes who take performance-enhancing drugs and the officials who try to catch them, each side is always looking for an edge. Now officials are worried by the potential for athletes to abuse experimental gene therapy methods, injecting genes that could, say, help a shot-putter throw that extra meter or a cyclist accelerate over that final hill.

Although legitimate gene therapy, which inserts into sick patients the genes they need to produce therapeutic proteins, has yet to be proven medically safe and effective, insiders say it's only a matter of time before athletes hijack the technology for their own benefit. To head off such abuse, the World Anti-Doping Agency, the Montréal, Québec-based organization that regulates the use of illicit substances in sport, is about to specifically ban athletes from injecting performance-enhancing genes; the agency is also offering funding for new ways of detecting such abuse.

There is no evidence that gene doping has already happened. But the worries are real. Several of the gene therapy trials under way involve genes for substances such as muscle growth factors and the red-blood-cell booster erythropoietin that could benefit athletes. And sports trainers have already started approaching gene therapists, say some medical researchers. "The leap from therapy to athletic enhancement is not a big one," says Theodore Friedmann, a molecular biologist at the University of California, San Diego, and a member of the anti-doping agency's Health, Medical and Research Committee. "It's going to be a problem because the technology is there."

The challenge to sports officials is that the products of injected genes could be harder to detect than drugs. The drug form of erythropoietin, for instance, is chemically distinguishable from its naturally occurring form. However, erythropoietin encoded by an injected gene looks identical to that encoded by a native gene.

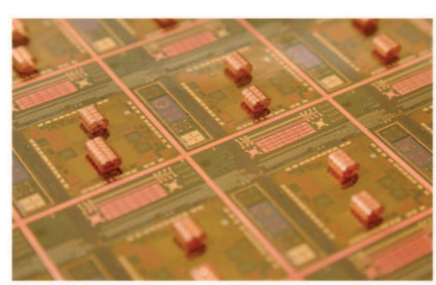
The anti-doping agency is considering several proposals for detection schemes. One method could involve magnetic resonance imaging: researchers would inject athletes with chemical labels that bind to specific muscle growth factors; high levels of those chemicals concentrated in a runner's legs, for example, might be a sign of gene doping. However, Barry Byrne, a researcher at the University of Florida School of Medicine who uses MRI in his own gene therapy experiments, says "such a high-tech approach may not be feasible in many countries." Even so, similar high-tech tools may be the best edge sports officials have in their race against doping. —*Alexandra Stikeman*

POP-UP RADIO PARTS

MATERIALS | **If chip makers like Intel are ever to realize their vision of squeezing an entire radio onto a silicon microchip—thereby making wireless devices far cheaper to manufacture—they'll need high-performance, microscale versions of all the parts that go into conventional radios *(see "Radio-Ready Chips," TR June 2002)*. That includes tiny inductor coils, which are basic components of the oscillators used to tune in specific wavelengths. But "high-quality coils have been difficult to integrate directly onto a chip," says David Fork, a physicist at the Palo Alto Research Center.**

Until now. PARC's solution: coils that "pop up" out of the chip's silicon surface. Fork and his coworkers have learned to take advantage of the previously exasperating tendency of very thin layers of materials like silicon to curl up under stress. The researchers build stress gradients into a thin film of metal alloy. They then etch two rows of strips into the film; when these strips are released from their adhesive base, they curl up into half-circles that meet at the top, much like binder rings—exactly the shape needed for inductor coils in silicon radios *(see photo)*.

Ultrasmall radios may not be the only application for these "stressy metals." "We see economic spillovers in other areas," says Michael Schen, a program manager at the National Institute of Standards and Technology in Gaithersburg, MD, which funded Fork's work. For example, Schen says, stressy metal strips on silicon could be patterned into a regiment-like formation of electrical connectors dense enough that each strip could drive a single pixel in an ultrahigh-resolution display. All of which could soon give "stress" a good name. —*David Cameron*



Stress causes PARC's coils to pop up from the top layer of a silicon chip and curl together.

COURTESY OF PARC (POP-UP RADIO PARTS); JAMES YANG (ILLUSTRATION)

Affinnova's software shuffles features such as a bottle's top, neck, label and base.

INTERNET SELECTION

PRODUCT DESIGN | Consumers seldom know exactly what they want in a product before they see it. But a software firm in Cambridge, MA, is out to solve that problem using concepts from—of all things—evolutionary genetics. Programmers at Affinnova believe that software based on so-called evolutionary algorithms can help participants in marketing studies sort through multitudes of design possibilities for products—be they toothbrushes or blue jeans—and zero in on the most appealing ones. The goal is to spare companies the task of building and market-testing every concept they dream up, a process so costly that "hundreds of interesting ideas are left on the cutting-room floor," according to Kamal Malek, Affinnova's chief technology officer.

Affinnova's software is derived from computer science techniques that aid decision-making in areas such as natural-language processing and robotic flight, where there is often no clear "right answer," and dozens, hundreds or thousands of factors must be weighed, tested and combined. Such programs treat each factor as a separate part of the solution "genome." They create a diverse population of solutions, test them against each other and let the "fittest" solutions recombine, to be tested again and again.

In Affinnova's system, a soda bottle's contours, color and label could all be varied, mixed and matched, and depicted with advanced imaging software. Paid test subjects connected via the Internet would approve or reject each design with a click of the mouse, and the software would generate new images using feature combinations that scored well—eventually leading, in theory at least, to a hit product. Affinnova says several makers of packaged consumer goods, including Procter and Gamble and Binney and Smith (makers of Crayola crayons), use the system regularly.

A number of competing companies are developing Web-based market research applications, but Affinnova stands out for its "very creative approach," says John Hauser, a marketing professor at MIT's Sloan School of Management. Technology like Affinnova's, Hauser adds, promises to "revolutionize the way data is gathered about customers." The next products Affinnova wants to evolve: consumer electronics and automobiles. —*Dan Cho*

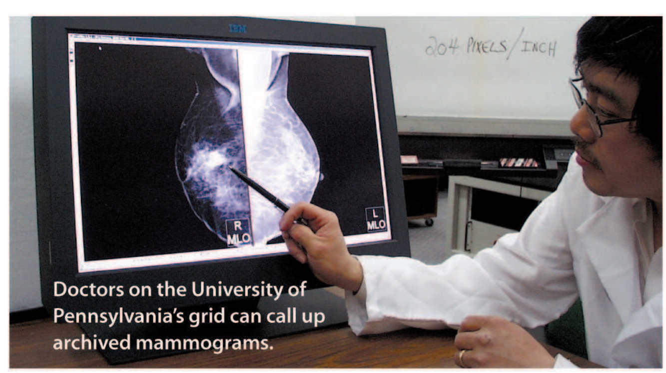
MAMMOGRAM GRID

COMPUTING | **A new digital image archive developed at the University of Pennsylvania could transform breast cancer diagnosis by allowing quick comparisons between a woman's latest mammogram and older ones. Once fully deployed, the archive should link thousands of hospitals across North America. That's a far cry from today's situation, where deteriorating x-ray films languish scattered in hospital basements, retrievable only by hand and frequently taking days to reach diagnosticians.**

Two advances are enabling the archive: proliferating mammogram machines that store scans as digital images and a new technology called "grid computing"—the sharing of varied high-end computing resources over the Internet and other networks. The archive, which received its first images in May, "really leverages advances in information technology to help in a clinical area that, frankly, suffers from problems in managing information," says Penn radiologist Mitchell Schnall. A team led by Schnall and Penn physicist Robert Hollebeek wrote software that collects data from digital mammogram machines, encrypts it for secure transmission to a central repository and indexes it for fast retrieval.

If that sounds unimpressive in the age of Internet movies, consider that the archive is designed to be scaled up to as many as 2,000 hospitals, and that the sites—the project currently includes hospitals in Chicago, Toronto and North Carolina—may have differing computer hardware, privacy policies and antihacker measures. Such hurdles have largely prevented physicians at different hospitals from using today's networks to share patient information.

IBM, which provided the servers and database software for the project, sees it as a major test of grid computing. "You could use [this system] to handle all types of image data," says Peter Ungaro, IBM's vice president of high-performance computing. "We really think grid computing can have a dramatic effect on health and medicine." —***Wade Roush and Alexandra Stikeman***



Doctors on the University of Pennsylvania's grid can call up archived mammograms.

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ON LOCATION

TELECOMMUNICATIONS | Wherever you go, there you are. But where is that? Two startups have come up with potentially more reliable ways of finding out. If adopted, both techniques could hasten the arrival of the U.S. government-mandated E911 system, under which all mobile-phone users must, by Dec. 31, 2005, have technology available to them that can transmit their locations to emergency-service providers.

Some cell phones are already equipped with Global Positioning System receivers, which reckon location from radio signals beamed from satellites, but they don't work well in buildings or urban canyons. Modifying cell phone towers to send special positioning signals is another proposal—but it would be costly.

Rosum, in Redwood City, CA, avoids these problems by taking advantage of the powerful signals coming from proliferating digital television transmitters. A Rosum-equipped phone finds itself by locking onto the synchronizing pulses broadcast between video frames by three different TV towers with known position and triangulating. According to Rosum, the system has pinpointed locations to within 20 meters in tests in the San Francisco Bay area. That's comparable to GPS accuracy; but because digital TV pulses are 100,000 times stronger than a GPS signal at ground level, the Rosum devices can function indoors or on big-city streets. "We looked at the sync signal," recalls Rosum cofounder and CEO Matthew Rabinowitz, "and we saw that we could slam dunk this problem."

A Dublin, Ireland-based startup has another way to score in the positioning competition. Digital Earth Systems is building a geographical database from the signal-strength measurements collected by wireless carriers as they scour their coverage areas for "holes." For any cell phone on the network, the combination of signal strengths from each of several nearby towers mathematically correlates with a unique geographical point. A prototype in Manhattan pinpoints a cell phone's position to within 100 meters, says president James McGeough.

Rosum's TV-based system is "very interesting, and I know of no one else working on it," says wireless analyst Rajeev Chand of Rutberg in San Francisco. Digital Earth's approach, Chand notes, has the advantage of a "very low cost of entry—basically the time to drive around and take measurements."

Rosum plans to deliver chips using its technology to cell phone makers by early 2004, a year ahead of the E911 deadline, and Digital Earth says its service is available now. Despite the ingenuity of their living-off-the-land approaches, however, neither of these systems is assured of market success; most wireless carriers are already settling on GPS as the best way to meet the mandate. But if satellite signals' weakness can't be overcome, it may be land-based technologies that ultimately help you find•• • • ••• ••••—*Herb Brody*

NANO LAB FOR ZÜRICH

NANOTECHNOLOGY | Considering that some of nanotech's most important advances were made a few train stops away at IBM's Zürich research labs, the Swiss Federal Institute of Technology's nanotechnology facilities have been surprisingly scattered and underequipped—until this summer. The institute has opened a $19 million nanotech lab in Zürich in an effort to establish itself as a major research center for the new atomic-scale technology.

The Swiss institute's commitment marks an important milestone for nanotech research in Europe, according to Gerd Binnig, the IBM physicist who coinvented one of nanotechnology's key tools, the scanning tunneling microscope. For the "very well established and somewhat conservative" institute to start a nanotech center is a sign that the technology "already is some kind of reality, more than a dream," Binnig says.

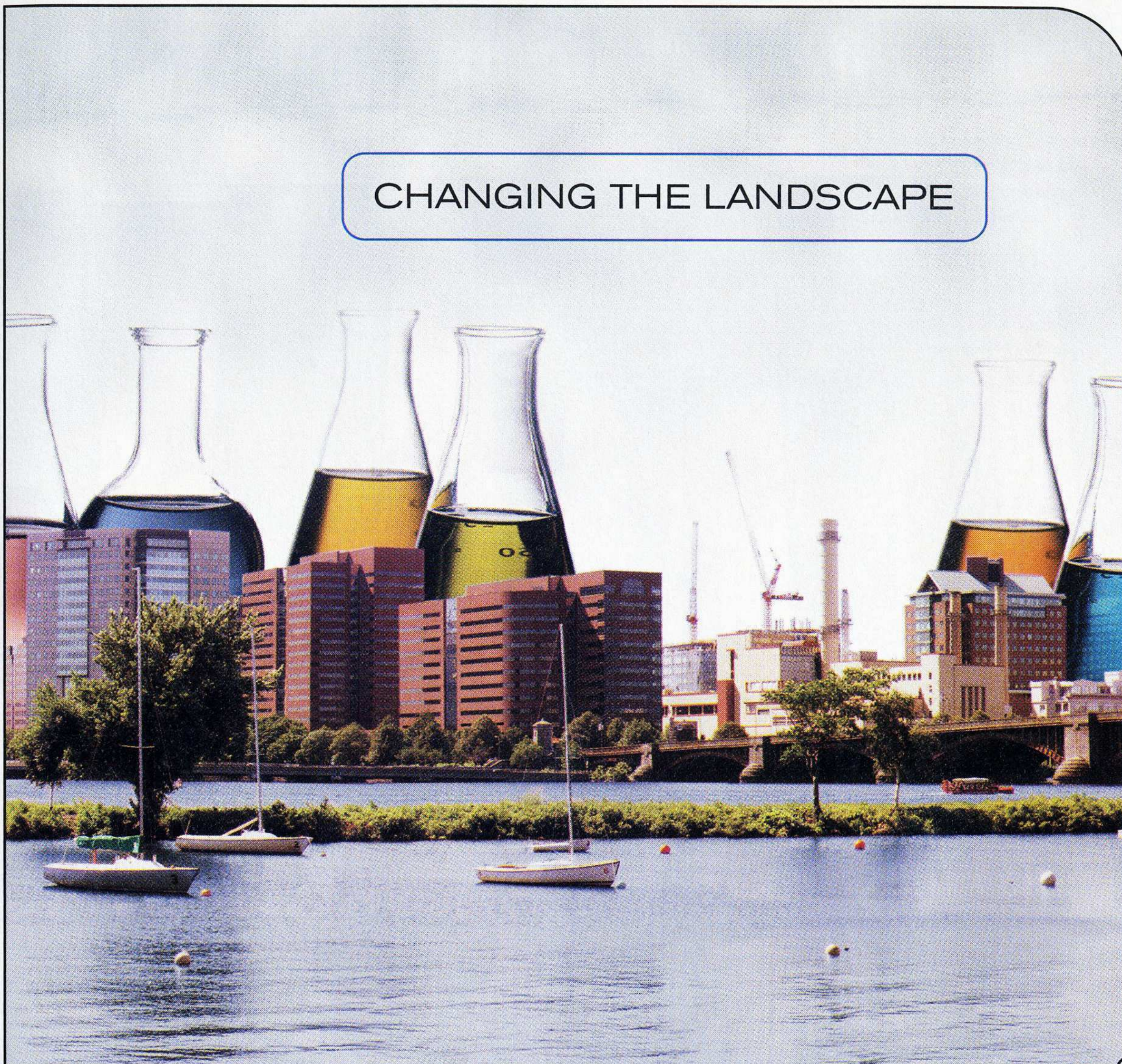
Indeed, the lab is part of the increasing investment in nanotech across Europe. Altogether, European governments are spending more than $350 million on nanotech R&D this year, up from $126 million five years ago *(see table)*. While these investments still lag behind those of the U.S. and Japanese governments, a new nanotech lab has now risen not far from where the world got one of its first glimpses of the nano realm.—*David Talbot*

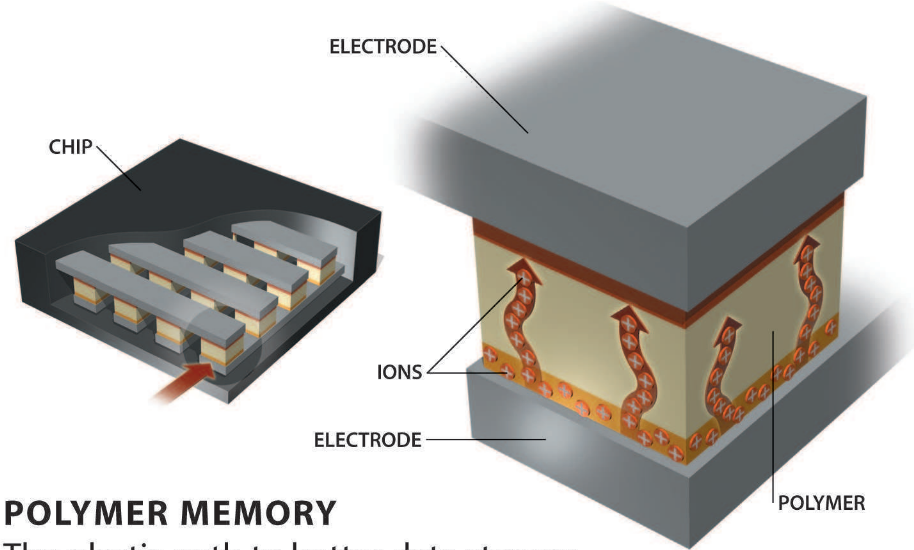
Global Growth in Nanotech R&D
(in millions of dollars)

COUNTRY/REGION	1997	2002
United States	432	604
Western Europe	126	350-400
Japan	120	750
South Korea	0	100*
Taiwan	0	70
Australia	0	40
China	0	40
Rest of world	0	270

* per year, for 10 years

SOURCE: NATIONAL SCIENCE FOUNDATION (NANOTECH R&D); ILLUSTRATION BY JAMES YANG


CHANGING THE LANDSCAPE



Ionic speed: In Coatue's memory chip (left), an electric field draws ions up through the polymer (right), increasing its conductivity; differences in conductivity represent bits of data.

POLYMER MEMORY

The plastic path to better data storage

While microchip makers continue to wring more and more from silicon, the most dramatic improvements in the electronics industry could come from an entirely different material: plastic. Labs around the world are working on integrated circuits, displays for handheld devices and even solar cells that rely on electrically conducting polymers—not silicon—for cheap and flexible electronic components. Now two of the world's leading chip makers are racing to develop new stock for this plastic microelectronic arsenal: polymer memory.

Advanced Micro Devices of Sunnyvale, CA, is working with Coatue, a startup in Woburn, MA, to develop chips that store data in polymers rather than silicon. The technology, according to Coatue CEO Andrew Perlman, could lead to a cheaper and denser alternative to flash memory chips—the type of memory used in digital cameras and MP3 players. Meanwhile, Intel is collaborating with Thin Film Technologies in Linköping, Sweden, on a similar high-capacity polymer memory.

Polymer microelectronics are potentially far less expensive to make than silicon devices. Instead of multibillion-dollar fabrication equipment that etches circuitry onto a silicon wafer, manufacturers could eventually use ink-jet printers to spray liquid-polymer circuits onto a surface. Polymer memory comes with an added bonus: unlike the memory in your PC, it retains information even after the power is shut off. Such nonvolatile memory offers potential advantages—not the least of which is the prospect of never having to wait around for a PC to boot up—and a number of researchers are working on various approaches *(see "Magnetic Random-Access Memory,"* TR *July/August 2002)*. But polymer memory could potentially store far more data than other nonvolatile alternatives.

Polymer memory stores information in an entirely different manner than silicon devices. Rather than encoding zeroes and ones as the amount of charge stored in a cell, Coatue's chips store data based on the polymer's electrical resistance. Using technology licensed from the University of California, Los Angeles, and the Russian Academy of Sciences in Novosibirsk, Coatue fabricates each memory cell as a polymer sandwiched between two electrodes. Application of an electric field to a cell lowers the polymer's resistance, thus increasing its ability to conduct current; the polymer maintains its state until a field of opposite polarity is applied to raise its resistance back to its original level. The different conductivity states represent bits of information.

Coatue's polymer memory cells are about one-quarter the size of conventional silicon cells. And unlike silicon devices, the polymer cells can be stacked to produce a three-dimensional structure. That architecture could translate into memory chips with several times the storage capacity of flash memory. By 2004, Coatue hopes to have memory chips on the market that can store 32 gigabits, outperforming flash memory, which should hold about two gigabits by then.

But turning polymer memory into a commercial product won't be easy. Memory technologies compete not only on storage capacity but on speed, energy consumption and reliability. "The difficulty is in meeting all the requirements of current silicon memory chips," says Thomas Theis, director of physical sciences at IBM's Watson Research Center in Yorktown Heights, NY. Until new memory materials are able to compete with the high performance of silicon, Theis notes, they are likely to be limited to niche applications.

One likely use is in disposable electronics, where cost, rather than performance, is the deciding factor. Researchers at Lucent Technologies' Bell Laboratories are working on polymer memory devices for use in identification tags. The polymer memory made at Bell Labs is still relatively slow by silicon standards, and anticipated capacity is only on the order of a kilobit. But, says Bell Labs chemist Howard Katz, the flexible and low-cost polymer memory devices could be "very attractive" for, say, identification tags meant to be thrown away after a few uses.

As polymer memory technology advances, it could pave the way to computers made entirely of plastic electronic components, from the display to the logic chip. That may be decades off, but as researchers push the bounds of polymers, the vision seems less far-fetched. And in the short term, Coatue says its polymer memory could be integrated into the existing silicon infrastructure. "The revolution has already begun," says MIT chemist Tim Swager, a scientific advisor to Coatue. *—Alexandra Stikeman*

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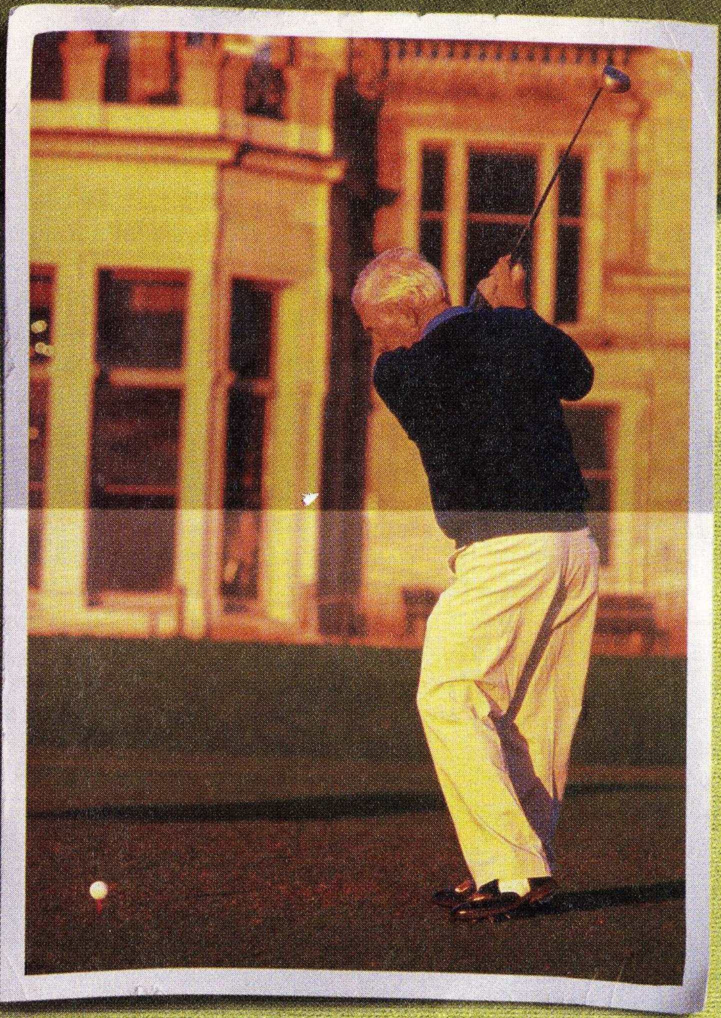

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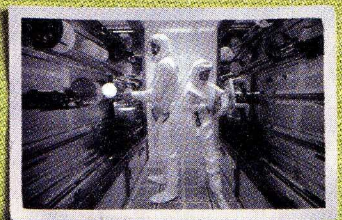

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FIREWALL FOLLIES

Do you use the Internet at work? I see lots of hands. You may not realize it, but your access to the Net is most likely mediated by some kind of firewall. Companies are spending thousands, even hundreds of thousands, of dollars on these systems—and trust them to protect their networks from snoopers and intruders.

That's a problem, because firewalls often provide a mere illusion of protection. They don't make business systems significantly more secure. And by focusing attention on defending the perimeter, rather than on defending information assets within an organization, firewalls foster lax internal security practices that magnify the damage that insiders can inflict.

What firewalls do accomplish, however, is this: they make the Internet more cumbersome to use. I recently visited a friend's firm in New York and wanted to check my e-mail, so I plugged my laptop into a network jack in an unused office. Access denied: my PC wasn't set up to work with the company's firewall. So instead of reading my e-mail, I occupied myself by sniffing the traffic on the office network and probing for a way out. (Had I been inclined, I could have read everybody else's e-mail—or done real damage.)

Firewalls are simple in concept. A typical firewall consists of a special-purpose computer that has two network plugs. One plug goes to the Internet; the other connects to a company's office network. The firewall is programmed with rules that determine what traffic is allowed to pass and what is to be blocked. For example, a firewall might be set up to allow managers in human resources to browse the Internet, or to access their desktop PCs from home, while permitting people in the corporate call center only to access their e-mail. The better firewalls log everything that moves across the boundary, giving companies a powerful tool for auditing online activity.

The great appeal of firewalls is that they are supposed to ease the job of corporate security. Instead of feverishly downloading and installing security patches to protect thousands of desktop computers and servers running a menagerie of operating systems, many organizations find it easier to simply trust the firewall to keep the bad guys out. The problem with this approach: bad guys are everywhere. Sure, some are on the outside of the company's network. But there are corrupt employees on the inside, too. And even well-meaning workers can have laptops that contract viruses during business trips—viruses that then infect the office network. This is why so many companies supposedly fortified with firewalls succumbed to attacks from computer viruses and worms like Nimda and Code Red.

The existence of firewalls has also allowed companies to neglect their internal security measures and to accept lower-quality software from their vendors. Instead of hardening their systems, many vendors now advise their customers to install their equipment "behind the firewall." This has long been standard practice for software suppliers delivering systems based on Microsoft Windows. Now it is becoming common for network-based management systems that are showing up in things like photocopiers, HVAC equipment and even elevators.

Organizations that rely on their firewalls build networks with hard, crunchy outsides but soft, creamy insides. Even worse, an elaborate, expensive firewall diverts dollars and attention from other measures that truly *can* improve security: good backups, pervasive encryption and employee background checks, for example. My friend's company should have turned off the Ethernet jack in that unused office—or I should have triggered an alarm when I tried to use it.

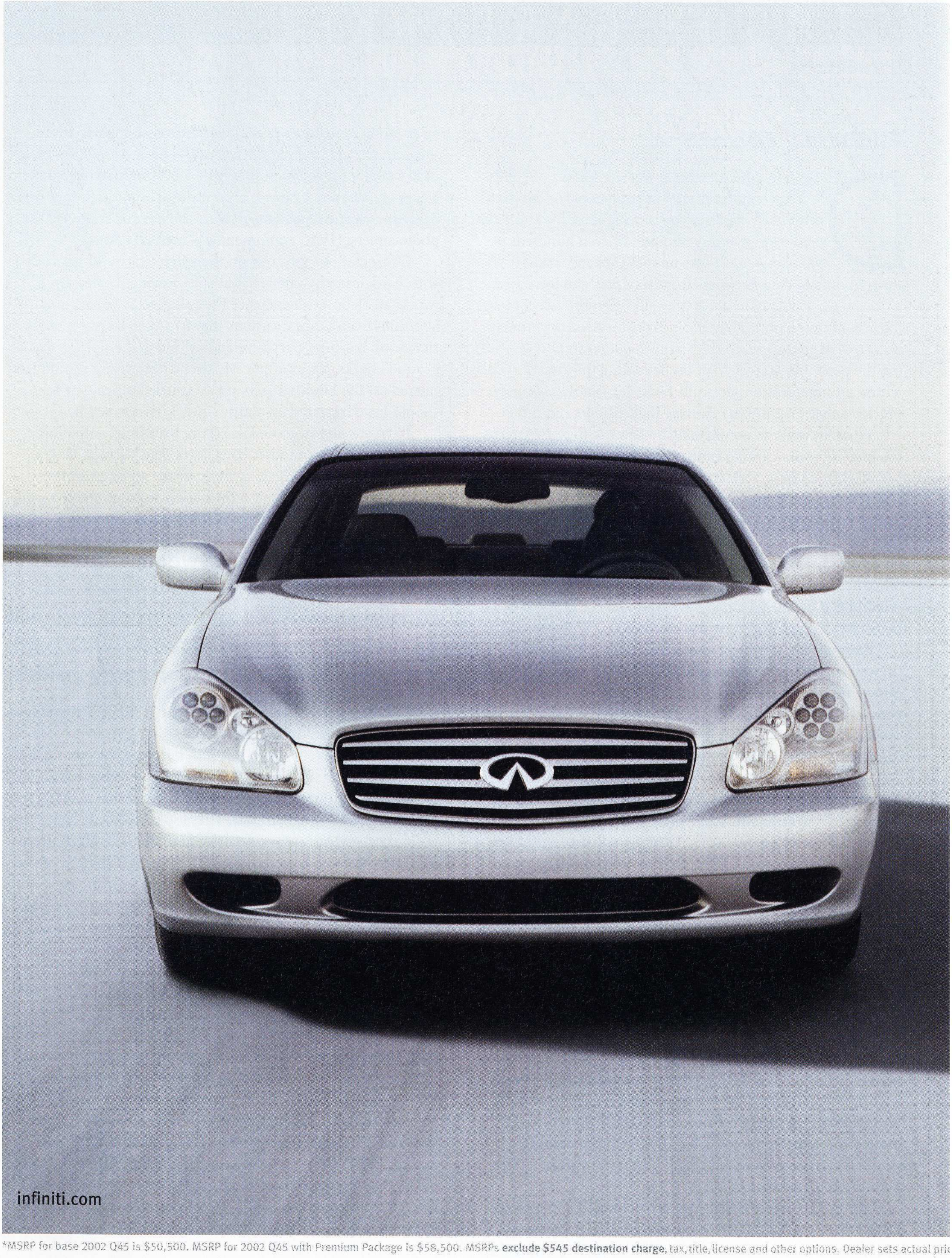
Firewalls also become less secure over time, a phenomenon observed by computer consultant Dan Farmer. Here's what typically happens: Somebody inside an organization needs to send some sort of information through the firewall—perhaps because the company is involved in a joint project

The bad guys are everywhere—intruders from outside a company's network and corrupt employees on the inside. Reliance on firewalls results in networks with hard, crunchy outsides but soft, creamy insides.

with another firm. To allow this transfer, a supposedly temporary hole is opened in the firewall. But that hole invariably remains in place long after it is no longer needed. After a few years, the typical firewall comes to resemble Swiss cheese.

Confusingly, there is one kind of firewall that actually can dramatically improve security. These so-called host-based firewalls are a second layer of security that mediates all communications between your desktop computer and the rest of the network. A good host-based firewall will warn you, for example, that the program you just downloaded is trying to open a connection to a pirate Web server in Russia; you can then choose to either allow the connection to go through or terminate it. Both Microsoft and Apple have primitive host-based firewalls built into the current generations of their consumer operating systems.

I'm certainly not advocating that businesses do away with their firewalls; many Microsoft operating systems are so vulnerable that there is no other practical way to protect them. But we need to build a new security paradigm. The core principle should be an assumption that every network is already compromised; systems should be designed accordingly. In practical terms, this means encrypting all information that passes over the network and equipping every computer with its own host-based firewall. This kind of belts-and-suspenders redundancy is not particularly elegant, but then again, neither is an armored car. TR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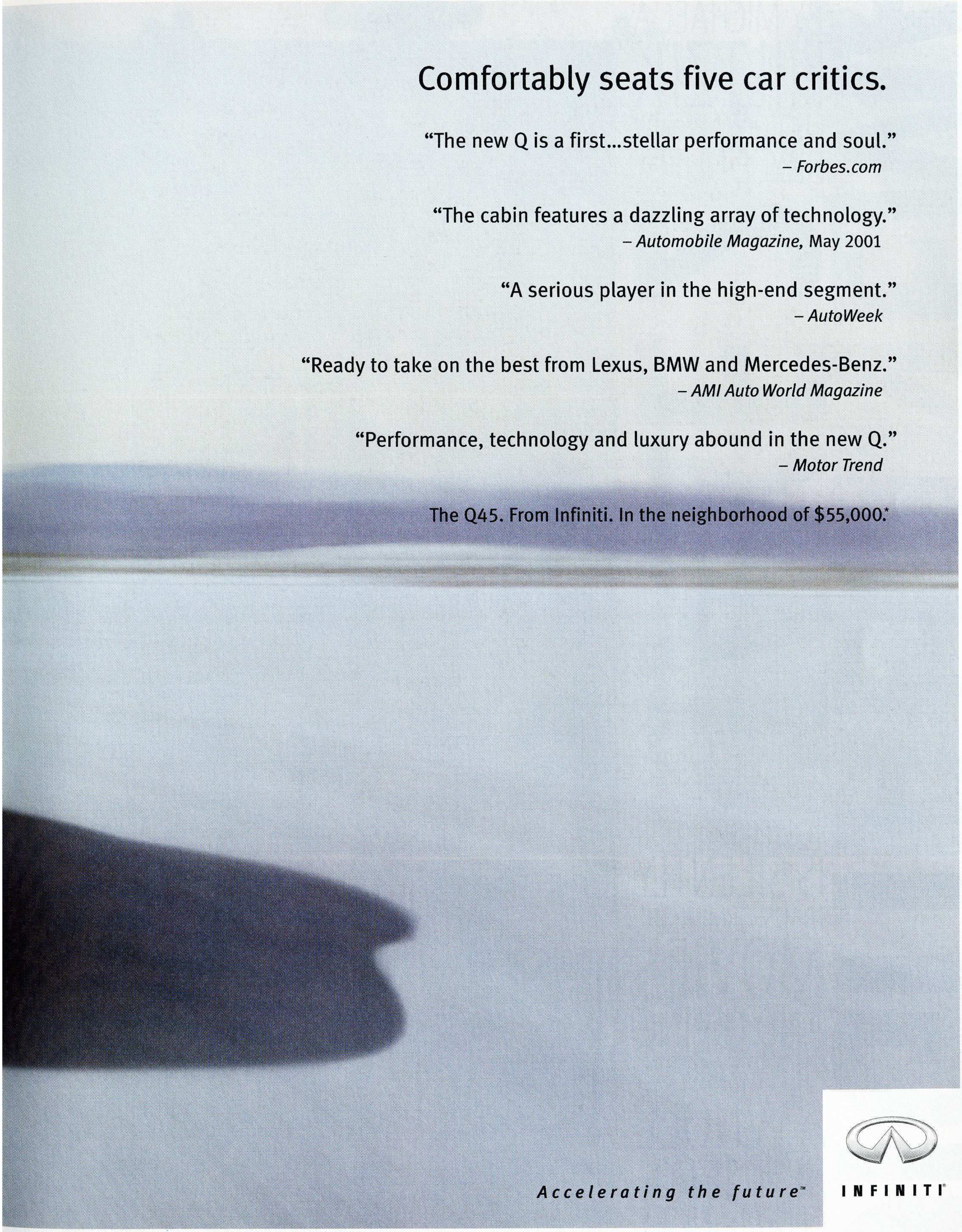
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DIGITAL CINEMA TAKE 2

BY MICHAEL A. HILTZIK
PHOTOGRAPHS BY BRYCE DUFFY

COMPUTERIZED POSTPRODUCTION IS SILENTLY TRANSFORMING THE MOVIES AND GIVING FILMMAKERS A WHOLE NEW SET OF CHALLENGES.

Image engineering: Digital artists turned lush fields dry for *O Brother, Where Art Thou?*, created a pristine print of *To Kill a Mockingbird* and synthesized much of the desert island in *Cast Away*.

Hollywood being a star-making machine above all else, it was not surprising that the buzz on 2000's release of *Cast Away* was all about the weight Tom Hanks gained and then dropped to give life to his character's years of privation. The real magic behind the film wasn't revealed until much later—that the island peak over which the hero clambered was a mud pile overlooking a California parking lot, and that much of the tropical environment seen on screen, from breakers to mountaintop, had been fashioned inside a computer.

Reliving the production, George Joblove breaks into a delighted grin. "Any shot that had ocean or sky in it," says the senior vice president for technology at Sony Pictures Imageworks, which created the visuals, "was pretty much a special effect." The film's software-generated scenes not only featured action and compositions that would have been impractical and expensive to shoot on location, but also contained elements such as windstorms and enormous waves that are virtually impossible to create in the real world.

That a tropical island could be manufactured so seamlessly out of pixels and algorithms testifies to the ascendancy of digital technology in Hollywood, where it has all but superseded the optical and photochemical manipulations that were state of the art as recently as 10 years ago. It's no secret that 3-D digital processing is responsible for some of the grandest effects of modern blockbusters, beginning with the dinosaurs of *Jurassic Park* and leading up to the careening space runabouts of *Star Wars: Episode II—Attack of the Clones.* But what's more remarkable is how thoroughly digital technology has taken over film editing, color adjustment and other components of the so-called postproduction process—including the subtle alterations, such as the erasure of television antennas from period backgrounds and support cables from acrobatic stuntmen, that lend verisimilitude to everything from drawing-room pieces to psychological dramas.

"We call them 'invisible effects,'" says Joblove, speaking from an office that overlooks the six-hectare Sony Pictures Entertainment studio complex in Culver City, CA. "Most are things you shouldn't notice and shouldn't know about, things that shouldn't draw attention to themselves."

Indeed, without most moviegoers' noticing, digital technologies have been slowly supplanting film-based processes that have been used since the 1920s. Imageworks' vice president of marketing and communication Donald Levy estimates that the movie industry now spends roughly half a billion dollars per year on visual effects—almost all of them digital. At many postproduction houses chemistry labs have given way to programming carrels in which computer science graduates write algorithms that will eventually simulate the wash of waves on a beach or the separation of a Saturn V rocket from its Cape Canaveral gantry—artists working in code rather than pen and ink.

And today there is scarcely a film lab in Hollywood that does not offer digital services—up to and including the restoration of archival films—to its industry clientele along with traditional developing, color timing and print services. One of the fastest-growing business lines at Technicolor, which pioneered the first two-color photochemical process in 1916, is the digital scanning of film prints in order to insert visual effects. Kodak, which sells some 80 percent of all the film stock used in U.S. movies, has hedged its bets by opening Cinesite, a Los Angeles- and London-based subsidiary that has become one of the most important and innovative purveyors of digital services—such as digital editing, special effects, and the creation of digital master copies of negatives and prints—to moviemakers.

But while large-scale digital modification of images is already rife in Hollywood, it has its limits. Clean digital files and hidden microchips haven't quite replaced reeking photochemical emulsions and temperamental celluloid stock, and the unalloyed enthusiasm many filmmakers felt for the new technology just a couple of years ago has evolved into a mature assessment of it as one tool among many, both novel and traditional. Directors and cinematographers who have worked in the new medium have generally found that its flexibility, while valuable, also comes at a steep cost.

Digital journey: Film negatives arrive at Kodak's Cinesite facility (left) and are transformed into digital masters by scanning experts (right).

PREVIOUS SPREAD: COURTESY OF TOUCHSTONE PICTURES (*O BROTHER, WHERE ART THOU?*); COURTESY OF CINESITE (*TO KILL A MOCKINGBIRD*); COURTESY OF SONY PICTURES IMAGEWORKS (*CAST AWAY*)

Reel to unreal: Even the fastest film scanners, like this 70-millimeter version at Cinesite, need days to digitize an entire movie.

Take Roger Deakins, an award-winning cinematographer who used digital technology to great effect in creating the distinctive look of the Joel and Ethan Coen Depression-era film *O Brother, Where Art Thou?* Deakins and the Coen brothers were determined to evoke the Dust Bowl by giving the whole film the faded look of an old-time picture postcard. This involved, among other effects, transforming the lush greens of vegetation into a sere tobacco-yellow in the film's exterior shots. While the judicious deployment of lighting and lens filters would have had the same effect, it would also have given other colors, especially skin tones, an unnatural tint. Instead, Deakins shot the entire film conventionally and had his negative digitized at Cinesite, where technicians then helped him tint out the greens without affecting the rest of the palette by adjusting the digital values of the pixels in each image—much the way audio engineers can boost the bass of a recording without changing the treble or midrange.

Although the process sounds straightforward, it was much more demanding than conventional photography. Among other things, Deakins realized that he should invest his negatives with the most highly saturated colors possible, to give the technicians the maximum amount of information to work with during the color correction process. At Cinesite, he supervised the alterations like a mother hen watching over her chicks.

"I was there every day for more than 10 weeks, from testing with camera negatives until the first print was out of the lab," Deakins says. This was necessary in part because the entire project was novel, even for Cinesite. But Deakins feels that because of its very power, digital color correction demands particular watchfulness. "There's so much that can be done with the technology that if you as a DP [director of photography] aren't there, your work easily could be ruined."

In the end, he concluded that such so-called digital mastering (the conversion of a sequence or an entire film to digital form) is useful only in special circumstances—as when striving for an effect that can't be reached through conventional means. "It

depends on what's right for the project, because I don't think the quality is as good as film. If you're not going outside straight RGB [red, green and blue] timing, I don't see much point in going the digital route."

"There's a tremendous amount of hype around the word 'digital,'" agrees Steven Poster, president of the American Society of Cinematographers. As director of photography on Sony's summer release *Stuart Little 2*, Poster also used a digital master in postproduction, since almost every frame includes the film's title character—a mouse created entirely in digital form—or one of his digital pals. "There are certain skills necessary to accomplish the shooting, making and coming out on the other end with a motion picture," Poster says. "One is cinematography. We say, if you know how to light it doesn't matter what medium you're shooting on. Likewise, if you don't know how to light it doesn't matter which medium you're shooting in." Today's filmmakers, in other words, must master not one technology but two—and then be willing to spend long hours bridging their incompatibilities.

FILM'S FIRM FOOTHOLD

The best way to grasp the degree to which digital technology has infiltrated moviemaking is to partition the life cycle of a feature into three phases: image acquisition (known in simpler days as "photography"), postproduction and exhibition.

Electronic technologies have made remarkable progress on some of these fronts—but overall, cinema hasn't changed as much as you might expect from all of this summer's buzz about digital movies. Most principal photography is still done on film, despite George Lucas's decision to shoot *Star Wars: Episode II* entirely using digital cameras. Cinematographers agree that digital hardware is getting vastly better, aided by the emergence of the so-called 24p process, which allows high-definition digital video to be shot at film's 24 frames per second, rather than the roughly 30 of conventional video (thus eliminating the need for complicated adjustments of frame rates). But even the best digital imagery still doesn't approach film's resolution and dynamic range in terms of color and contrast.

Dialing tones: Colorist Jill Bogdonawicz and her dad Mitch, a Kodak researcher, apply color effects in the Datacine suite.

"There's still room in film to carry information beyond the capability of the eye to see it," says Brad Reinke, manager of digital restoration services at Cinesite. "Digital's not nearly there."

At the other end of the production process—your neighborhood movie theater—digital technology has barely made any headway. As of this summer only 100 or so of the country's 35,000 screens were equipped for digital movies—whether downloaded via satellite or spooled off high-density digital discs resembling DVDs. Those that were used a Texas Instruments system based on arrays of microchips, each with about a million microscopic mirrors that pivot toward or away from the screen thousands of times per second *(see "Digital Movie Projection,"* TR *March 2001)*. Digital projection is jiggle free, and unlike film projection, it doesn't degrade the print with every showing. But in part because digital projection does not create as unmistakable an improvement in the viewing experience as, say, the talkies did over silent films, theater chains are unwilling to foot the bill for the new projectors, which cost at least $100,000 per screen and might have to be upgraded every few years. Conventional film projectors, which last 20 years on average, cost $30,000.

"Digital cinema could never drive enough extra traffic through our box offices and to our concession stands to make up the difference," John Fithian, president of the National Association of Theater Owners, told a Washington, DC, technical conference last year.

Still, almost everyone in Hollywood agrees that in postproduction, digital is well on its way to becoming the state of the art. Film editing today is done almost entirely through virtual cutting and pasting on video screens, which replaces the tiresome manual method of slicing up celluloid film strips and splicing them back together with tape.

COMPLEX FX

Special effects—everything from plane crashes to acrobatic stunts to alien life forms—are now customarily computer generated, thanks to software tools like Pixar's RenderMan, or like Maya, perhaps the most widely used application for 3-D imaging. The product of Silicon Graphics subsidiary Alias|Wavefront and a direct descendant of the program that produced the dinosaurs of *Jurassic Park* in 1993, Maya is esteemed by digital-effects teams not only for its comprehensive scope and power, but for its compatibility with the special-purpose "plug-ins" (mini-programs that interact with and enhance the main software) that special-effects departments often devise to meet particular needs on feature projects. It's not unusual to hear visual-effects artists comparing the merits of, say, the ocean effects plug-in Imageworks devised to generate the breakers and swells in *Cast Away* and the one developed by Warner Brothers for *The Perfect Storm*.

Even more remarkable is the extent to which digital artists are using their tools to give life to animated characters. Every year brings improvements in the rendering of movement and organic textures like skin and hair. "We do almost all our modeling and character animation with Maya," Sony's George Joblove is explaining one afternoon as he escorts me past the darkened warrens of Imageworks' animation floor, where the finishing touches are being made on *Stuart Little 2* weeks before its

Rack room: Playback decks feed data to Cinesite's editing suites.

scheduled release. He pulls aside a curtain to reveal a glimpse of a Maya artist working on a scene a few seconds long in which a complacent Stuart Little is suddenly snatched out of the frame by a set of talons. The scene plays over and over again as the artist refines the details.

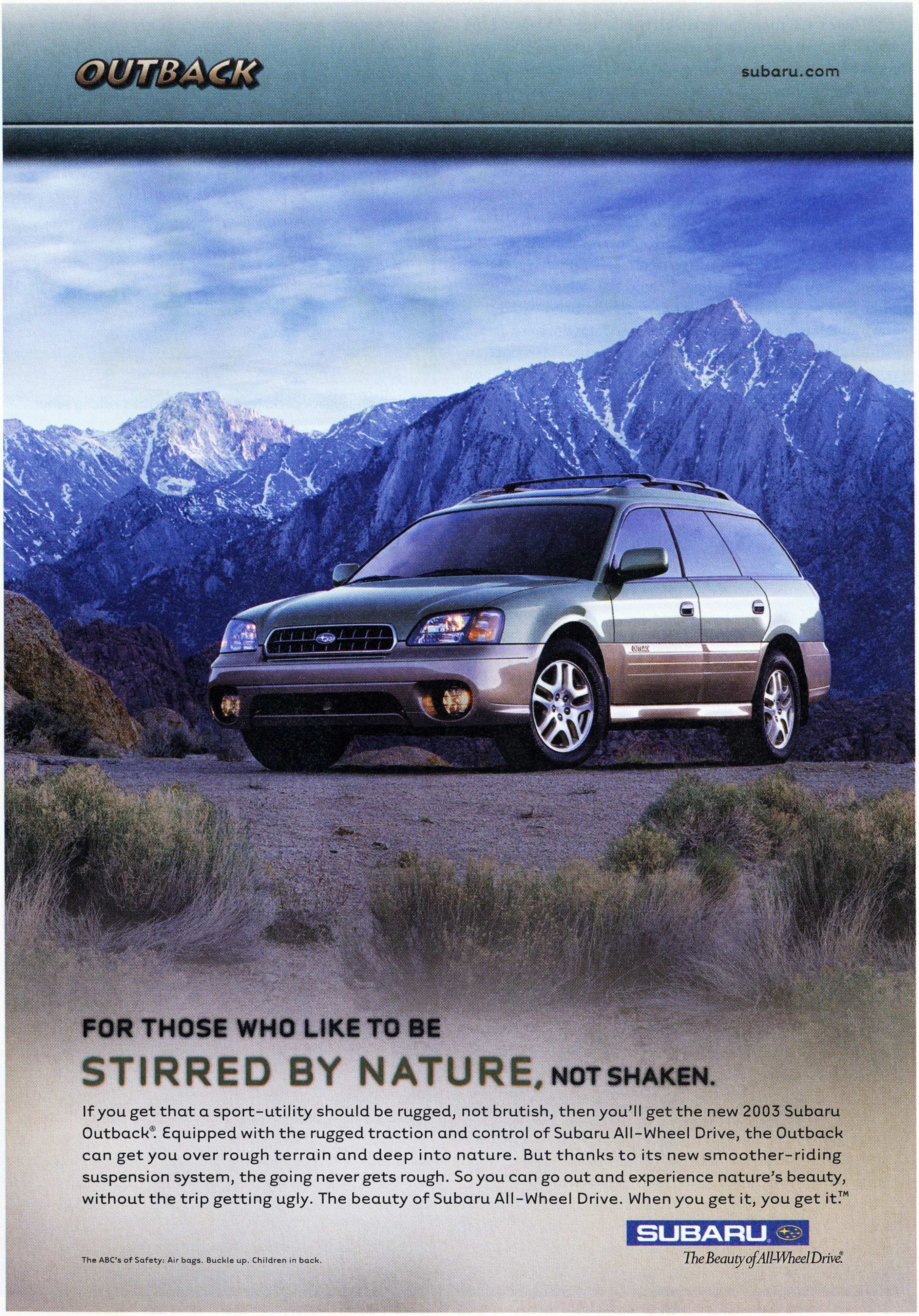
"We have more than two dozen software engineers," Joblove continues as we tour this particular nexus of the Hollywood Hills and Silicon Valley. At any given time, he notes, some might be deployed to work on the effects for a single film, others on software that the firm will use on dozens of projects. Some of these, such as code writers and database specialists, can be found in any highly computerized organization; others, the more artistic, have expertise that can only be found in a facility like Imageworks.

I ask which is more important, artistic talent or coding skills.

"We span the whole spectrum—people who are just engineers and couldn't draw a stick figure, and others who are talented artists and never used a computer before they came here. And in the middle," says Joblove, "are a few people working on shots who have a strong and deep understanding of the science and the software and the art."

This precious breed is actually becoming more and more common in Hollywood, fueling a range of digital-movie companies from Efilm, which has developed its own laser recording technology for transferring digital images back to film, to Rhythm and Hues, where one specialty is animating unusual characters such as *Harry Potter*'s Sorting Hat—a mouthy piece of millinery that, in the judgment of the *New York Times*, had "more personality than anything else in the movie" *(see "Digital Movie Stars," p. 43)*. But it may be at Cinesite's hangar-sized facility, a few miles north of Imageworks and not far from the corner of Hollywood and Vine, that the virtues of digital postproduction are most vividly on display—along with the difficulties.

The compromises begin in Cinesite's scanning room, where technicians convert film images to streams of digital bits by playing a laser beam over the original frames. Because digital video images have an inherent "edginess," film converted to video at the standard resolution (2,048 pixels wide by 1,556 deep, known as "2K") tends to look somewhat soft focused. That failing can be overcome by scanning at 4K—roughly 4,100 pixels across by 3,000 deep—but this generates a data file so big that a standard



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feature film would take 12 full days to scan. The larger digital files also impose a huge cost in storage requirements and processing time. Since the difference in image quality is almost imperceptible in a movie theater, 4K is only used for the most exacting projects, such as the conversion of *Fantasia* and *Apollo 13* for Imax presentations, where the giant screen would render even a minute loss of detail spectacularly visible.

After they leave the Cinesite scanning room, digital files continue along any of three production routes: to the insertion of visual special effects; to digital mastering, which allows color correction and conversion to DVD or video formats; or to the company's restoration service. The special-effects artists, who must carefully integrate the computer-generated objects in a frame with the real ones, get much of the glory once a film's publicity is under way. But the color timers and other professionals who oversee digital mastering probably contribute more to a film's overall look. During mastering, Cinesite's technicians use Kodak's Cineon system to adjust color values to avoid distracting video phenomena such as banding, in which slight gradations of brightness create contour lines, and clipping, in which the detail within bright images bleaches out. By adjusting the brightness of digitized images to a logarithmic curve—compressing the amount of information at the dark end of the scale and expanding it at the bright end—the system "matches the eye's perception," explains Steve Wright, Cinesite's technical director for 2-D.

RESTORED TO LIFE

But it may be Cinesite's digital restorationists who work the biggest technological miracles from day to day, making old, unviewable films look as new as they did the day they were printed. Restoration, in fact, is the one area where digital technology is close to an unadulterated blessing, for it gives technicians an unprecedented ability to remove defects caused by production mistakes or the ravages of time.

In a room rimmed with computer workstations, Corinne Pooler is painstakingly restoring a sequence from the classic 1962 film *To Kill a Mockingbird*, which Universal Studios is planning to rerelease in a pristine theatrical print. Because *Mockingbird*'s original negative had been damaged beyond usability, the restorers are working from two fine-grain prints unearthed in Europe and the United States and subsequently digitized by the company's scanners. Each print has its own myriad imperfections, however, which presents Pooler with the challenge of assembling one clean print from the undamaged portions of the two others.

The secret weapon is another program called Moviepaint, which Kodak specifically designed for Cinesite. On her monitor, Pooler displays a frame showing a clapboard house on the left, the branches of a spreading oak on the right, and along the frame edge the large, ugly blotch that is her quarry. Pooler carefully aligns the digital image of the previous frame over the stained image. Then she launches a function that allows her to import the pixels from the clean frame into the stained image, in effect erasing the blotch.

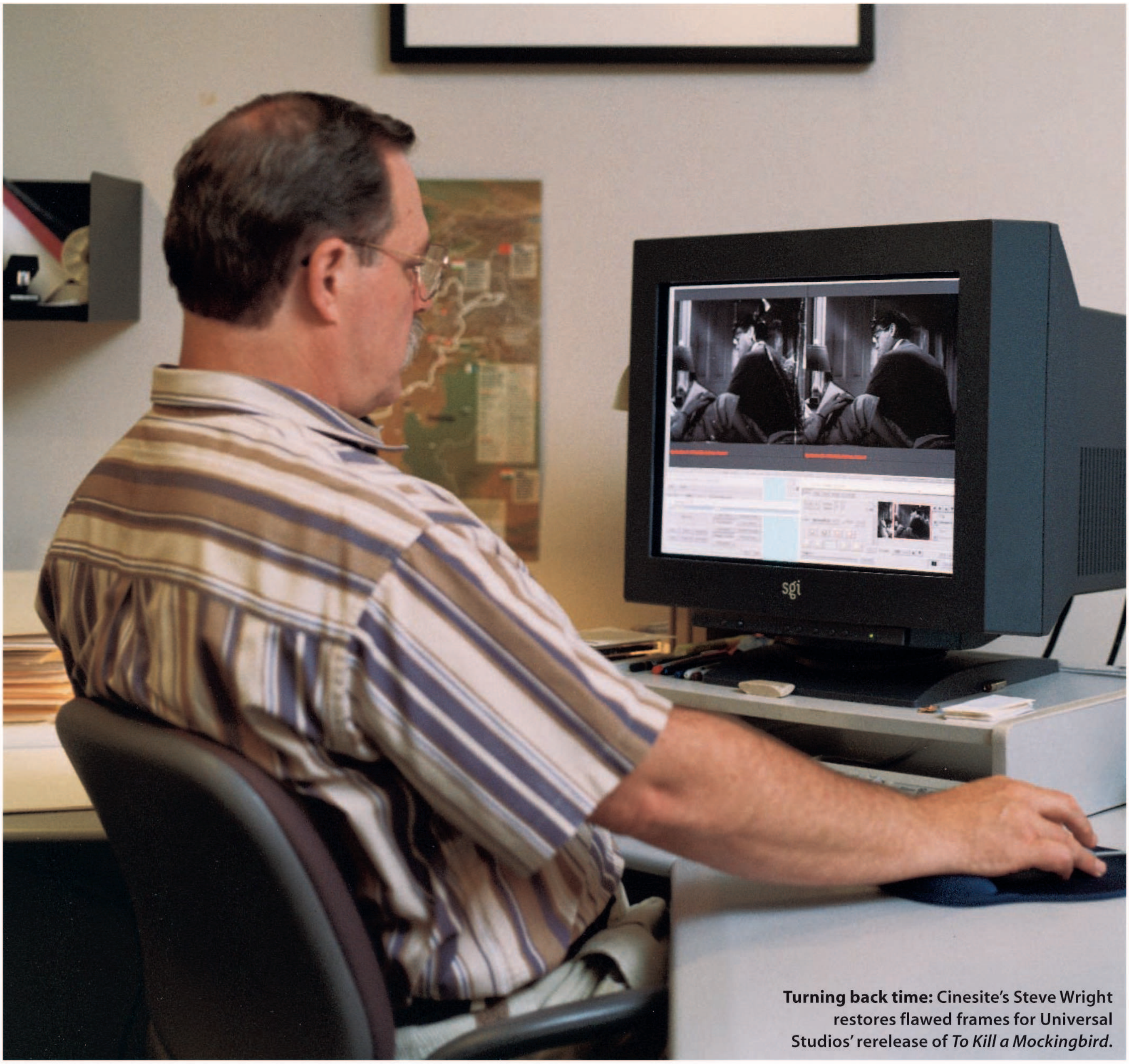
"It can be tedious," she says of a process that will have to be repeated, with minute variations, on thousands of scratches, stretches, dust globs and breaks. (A Cinesite program called Bitzer automates much of that process, but only manual work using Moviepaint can correct every flaw.) Pooler, nevertheless, is well aware that she holds a job that would not exist at all but for digital technology. Seven years ago, she explains, she was a housewife with a job with her local school board. As it happened, her husband, Jerry Pooler, creative director for digital restoration services at Cinesite, was beginning work on the restoration of *Sleeping Beauty*.

"I was off for the summer, and Jerry needed people to help paint out dirt hits," Corinne recalls. "He told me, 'If you can paint 150 frames a day we'll keep you. If not, I'll have to fire you.'" Pooler had no training in art or computer science, but she did have an eye instinctively capable of distinguishing between the minuscule details on a frame that are actually part of the image and the imperfections that call for obliteration.

In this craft an innocent misjudgment can wreck hours or days of work. Pooler recalls the time her team was called upon to paint out the vestiges of stunt gear from a 3,000-frame paratrooping sequence from a big-budget adventure movie.

Digital Movie Stars

NAME	LOCATION	SPECIALTIES	RECENT FILM PROJECTS
Cinesite	Los Angeles, CA	Digital mastering, visual effects, film scanning and recording, restoration	*O Brother, Where Art Thou?*, *Band of Brothers*, *Traffic*, *Planet of the Apes*, *Pleasantville*
Efilm	Hollywood, CA	High-resolution scanning from film to digital, laser recording from digital to film	*From the Earth to the Moon*, *Batman and Robin*, *Contact*, *Titanic*
Sony Pictures Imageworks	Culver City, CA	Scanning, color timing, modeling, character animation	*Spider-Man*, *Cast Away*, *What Lies Beneath*, *Stuart Little 2*, *Charlie's Angels*
Industrial Light and Magic	San Rafael, CA	Digital image acquisition, digital editing, visual effects	*Star Wars: Episode II—Attack of the Clones*, *Star Wars: Episode I—The Phantom Menace*, *Pearl Harbor*
LaserPacific Media	Hollywood, CA	High-definition postproduction, conversion of studio films to DVD	*Austin Powers: The Spy Who Shagged Me*, *Lost in Space*, *Wag the Dog*, *Magnolia*
Pixar	Emeryville, CA	RenderMan character-rendering software, feature-film animation	*Toy Story*, *Toy Story 2*, *Monsters, Inc.*, *Pearl Harbor*, *The Perfect Storm*
Rhythm and Hues	Los Angeles, CA	Character animation, visual effects	*Harry Potter and the Sorcerer's Stone*, *Men in Black II*, *The Sum of All Fears*, *Hollow Man*, *Babe*



Turning back time: Cinesite's Steve Wright restores flawed frames for Universal Studios' rerelease of *To Kill a Mockingbird*.

"Six of us divided the work. The first person saw a line of tiny black spots in the image and painted them out of the frame. The next person took a look and said, 'You erased all the parachutes!'"

MIXED MEDIA

The inadvertent erasure of real-world objects is only one of the occupational hazards awaiting moviemakers as digital technology continues to spread.

"Increasing technology always yields increasing complexity," says Daniel Rosen, Cinesite's chief technology officer. "If you're in a film theater and there's no image, your eyeballs will tell you what's wrong—a lamp burned out, or the film broke. If you're in a digital theater, what happened? Was the satellite down? Or the server? Or is there an encryption problem?"

A former TRW engineer, Rosen is Cinesite's resident technical visionary and voice of realism—equally alive to the virtues of digital technology and to its shortcomings. On the plus side, he says, is the incredible flexibility producers will gain from having digital negatives of their films, which they can feed into a multitude of formats, be they theater prints, DVDs or TV broadcasts.

On the other hand, Rosen doubts that artists or audiences will soon want to give up the unique sensory qualities of film. "If we look decades ahead, people will come to realize that digital [photography] is another way of doing things, but film will give you a different organic look," he says. "It's like oil paint and acrylic. Digital has a different texture."

And just as acrylics, watercolors and other media haven't replaced oils, digital movies may never fully replace film. More likely, the two media will coexist, with digital's practical advantages and differing qualities widening directors' and cinematographers' artistic and logistical options as the technology advances. Think of it this way: if Sony Pictures ever develops a *Cast Away 2*, and the producers discover that a digital Tom Hanks can shed 25 kilograms instantly, rather than dieting for a year, then the island may not be the only thing that's virtual. TR

Molecular view: Computer modeling of nano materials, like that done by Seung-Hoon Jhi, can substitute for experiments.

BY PETER FAIRLEY

NANOTECH BY THE NUMBERS

Computer simulations could greatly speed up the invention of nano materials for everything from ultrasensitive sensors to more efficient ways to store hydrogen fuel. Or at least one nanotech startup hopes so.

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

In his cramped cubicle at Nanomix, a nanotechnology company in Emeryville, CA, just across the bay from San Francisco, theoretical physicist Seung-Hoon Jhi peers at a computer model of a hydrogen fuel tank, carefully tracking the movement of individual molecules. As he raises the temperature of a simulated sheet of boron and nitrogen atoms from a frigid 50 Kelvin to a slightly less chilly 80 Kelvin, he watches the reaction of a handful of hydrogen molecules dotting its surface. The boron nitride sheet undulates, yet the hydrogen molecules hold fast. It's an encouraging sign in a virtual experiment that may have just saved weeks or months of painstaking experimental testing in Nanomix's effort to develop more efficient hydrogen storage materials for fuel cell cars.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It's cyberdreaming, of course. But Jhi and his Nanomix colleagues are so confident in the veracity of this computerized modeling, pieced together from precise calculations of the behavior of individual atoms, that they are using the simulations to design and test materials that have never been made before—materials whose ordering at the nanometer scale (a nanometer is a billionth of a meter) can produce properties useful in applications ranging from ultrasensitive sensors to flat-panel displays to stealthy coatings for war planes. Down the hall, less than 15 meters from Jhi's cubicle, the company's experimentalists are busy working in the lab to synthesize the most promising results of the modeling.

While Nanomix is just one of several recent startups hoping to exploit nano materials, the company is betting it has an edge: the skill to both virtually design the materials—without so much as stirring a beaker—and then go into the lab and make them. Its cofounders—theoretical physicist Marvin Cohen and experimental physicist Alex Zettl, both from the University of California, Berkeley—have been collaborating on such alchemy for over a decade. Now they are hoping to leverage that expertise as the basis for a nanotech business. "Our goal is to have the first working nano components on the market," says Nanomix CEO Charles Janac.

Designing materials on computers has tempted industrial researchers for more than a decade. In theory, at least, the idea is simple enough: using the rules of quantum mechanics it is possible to calculate the behavior of the electrons that swirl around an atom. Given enough computing power, one should be able to use such calculations to design a material atom by atom, building in desirable properties by adjusting the electronic profile. The problem is, the properties of materials result from the interactions of a huge number of atoms. And even today's most powerful supercomputers struggle with quantum calculations involving more than five or six hundred atoms, severely limiting the ability to design new materials.

But nano materials, which are often isolated molecules—or molecules whose properties arise from limited interactions—make a far easier target for computers.

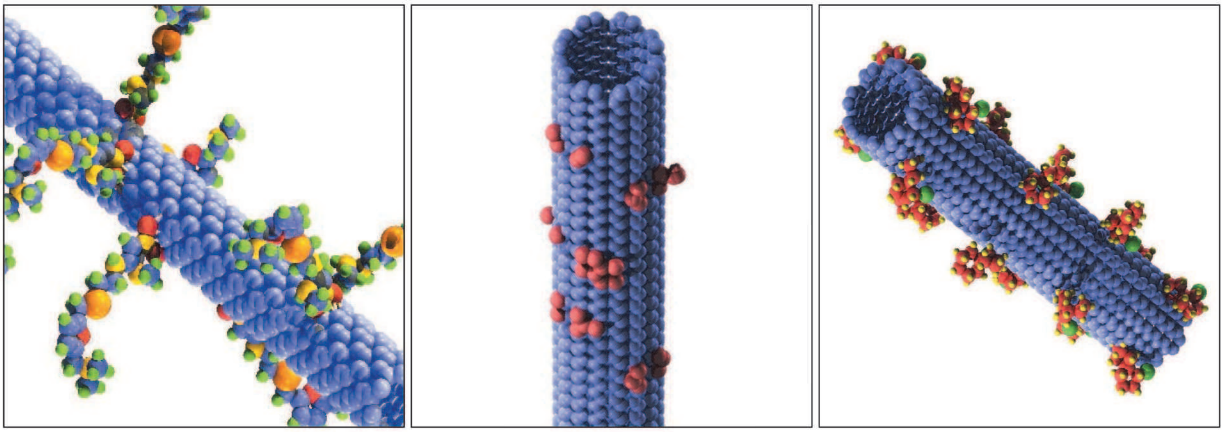
NANOMIX HOPES TO SOON BECOME A VIABLE NANO BUSINESS BY SELLING SENSORS. NEW NANO MATERIALS FOR FUEL CELLS AND COMPUTERS WILL TAKE LONGER.

Indeed, in many ways, quantum modeling is turning out to be an ideal way to explore the nano world *(see "Leaders in Quantum Modeling," p. 52)*. The "predictive power" of nano modeling, says James Tour, a chemist and leading nanotech researcher at Rice University in Houston, "is turning out to be tremendous."

Nanomix believes it is just this predictive power that will allow it to revolutionize the discovery of nano materials. Thanks to a head start from its computer simulations, the company, which started up in 2000, is already engineering tiny gas sensors that use carbon nanotubes—molecules just a few nanometers wide, with walls an atom thick—to detect dangerous gases. By the end of next year, Nanomix plans to begin selling these nanotube-based sensors to detect gasoline vapors—protecting refineries, chemical plants and pipeline stations from leaks. Each sensor should cost 10 times less than a conventional leak detector and operate for a year on a watch battery. Linked to wireless transmitters no bigger than postage stamps, they could be scattered by the tens of thousands, blanketing an industrial facility—or squeezed into leak-prone valves to ferret out failing seals, something not possible with far larger and more expensive conventional sensors.

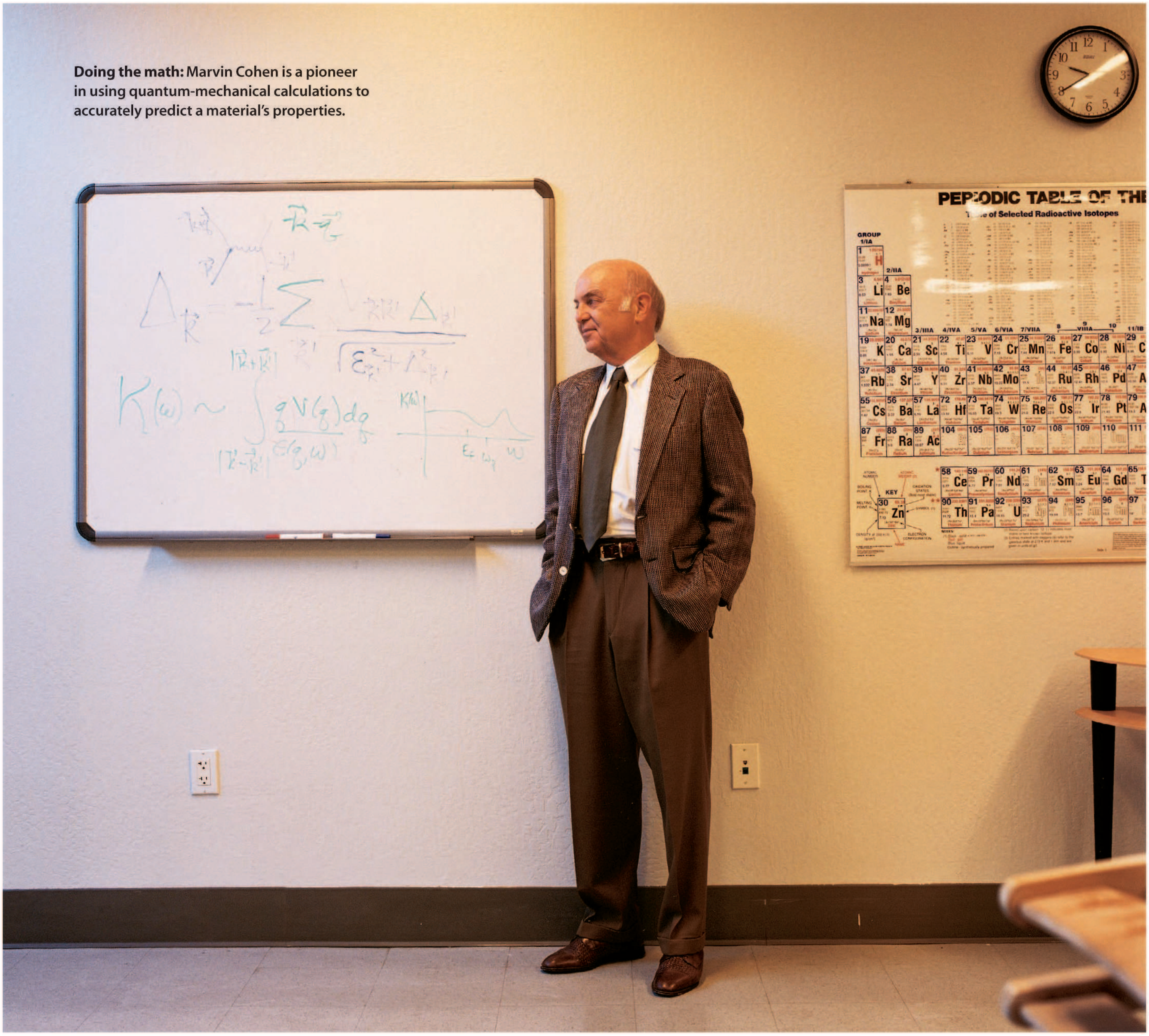
At the same time, Nanomix is drafting designs for novel nano materials for hydrogen fuel storage—materials with an even greater ability to store hydrogen than the boron nitride sheets on Jhi's screen. If these materials become reality, they could dramatically increase the performance of fuel cell cars, finally making automobiles that run on hydrogen fuel commercially practical. The company has also begun to ponder how novel nano materials like nanotubes could be used in tiny computing devices.

Nano materials for fuel cells and nano computers will likely take years to develop. But Nanomix believes its plan to begin selling sensors and other early applications of nanotech will make it a viable business long before then. "People keep saying nanotechnology is a long way out, and it is in the sense that it's a long-term trend that's going to have a huge impact on the world economy. But some of the early applications are just 18 months away," predicts Janac.



COURTESY OF NANOMIX

Nanotube preview: Simulations of carbon nanotubes show binding of gas molecules (center) and attachment of organic molecules (left and right).



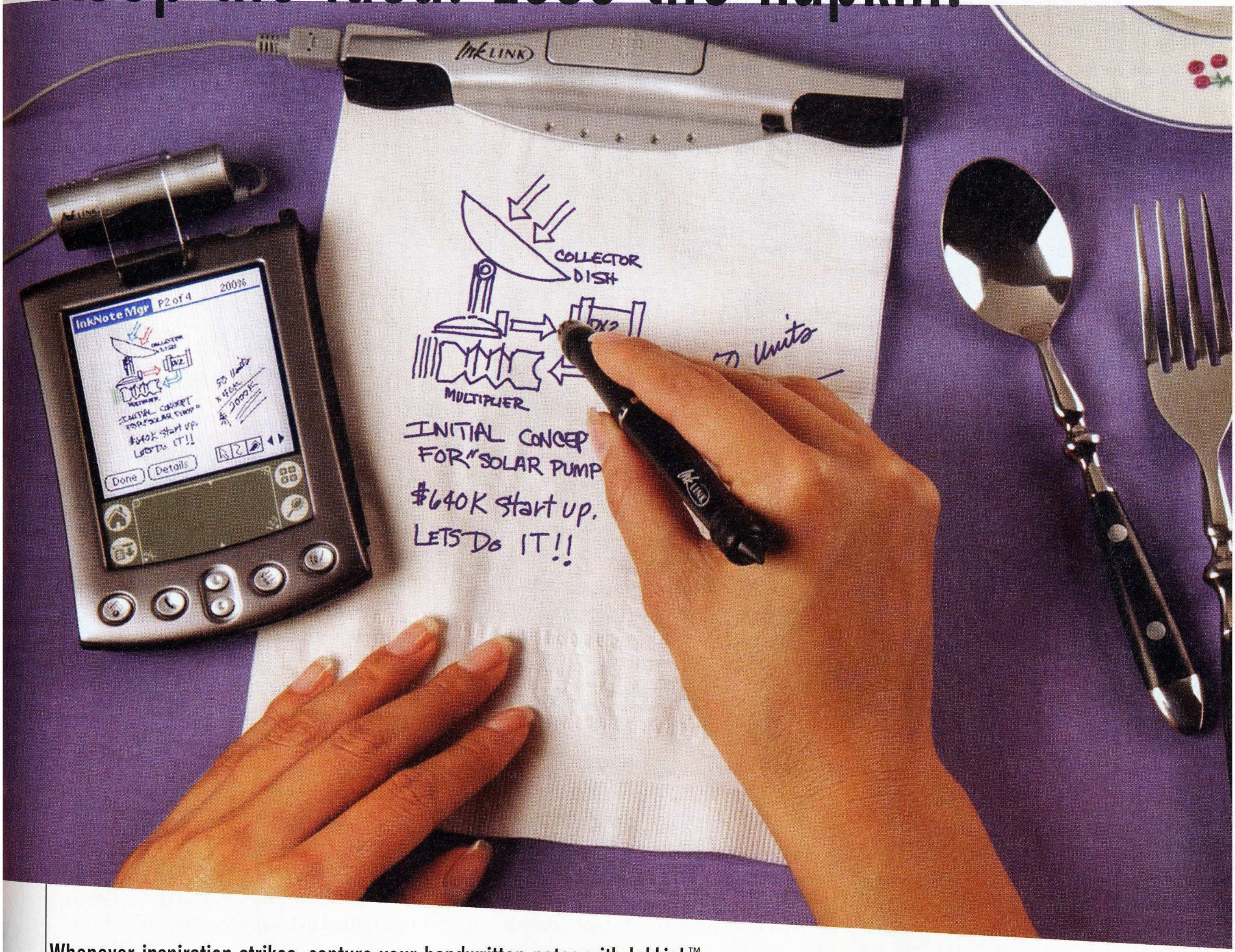
Doing the math: Marvin Cohen is a pioneer in using quantum-mechanical calculations to accurately predict a material's properties.

Sensing Success

Inventing a new material, say a new polymer or metal alloy, has never been easy—and is often more a case of serendipity than theoretical design. Even at leading industrial facilities such as DuPont's central research lab, which has invented many of today's most important polymers and high-tech materials, the process is often a hit-or-miss endeavor governed more by the instincts of experimentalists than the calculated predictions of theorists. At the nanoscale, however, the instincts of researchers often begin to fail, as the strange rules of the quantum world take over. "We're getting into areas where our intuition, which is often based on our prior experiences, is really quite deficient," says Ed Wasserman, science advisor to DuPont central research and development.

It is, however, a place where theoretical quantum physicists feel right at home—a realm where they can play god, creating new materials by simply shuffling around atoms. One of those gods is Nanomix cofounder Cohen, a pioneer in quantum modeling. In the 1960s, Cohen had the insight that since it is only an atom's outermost electrons that interact to give a material its properties, it is possible to greatly simplify the calculations needed for simulations by dealing only with those electrons. This mathematical shortcut revolutionized quantum-mechanical modeling. "If you do an all-electron calculation, it's almost like trying to find the weight of the captain of a ship by weighing the ship and then weighing the captain with the ship," explains Berkeley physicist Steven Louie, an advisor to Nanomix. By in essence weighing the captain directly, Cohen's software now makes it practical to use a PC to quickly crank out predictions on nano materials with novel combinations of electronic, magnetic and light-handling properties.

Keep the idea. Lose the napkin.



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But Cohen also realized that such simulations are only as real as the skills of the experimentalists down the hall. So in the early 1990s, he began collaborating with Berkeley colleagues, like Alex Zettl, who were experienced in synthesizing novel materials. The discovery—and actual synthesis—of boron nitride nanotubes in 1994 was one early success. Cohen, pondering the atomic structure of boron nitride sheets, realized that it should be possible to roll up the sheets to form cylindrical molecules. Other researchers had recently made similar molecular tubes from carbon, but no one had extended the technique to boron and nitrogen. Cohen and his students booted up their models and calculated that boron nitride nanotubes would not only be stable but would exhibit interesting electrical properties. Within a year, experimentalist Zettl had found a way to make the novel nanotubes and affirmed the predicted properties.

A neat scientific trick, for sure, but how do you turn that type of physics wizardry into a business?

The immediate challenge for researchers at Nanomix is to perfect the sensors that Janac has promised to begin selling next year. So far, Nanomix's theorists have identified the specific types of nanotubes that would react most sensitively to the hydrocarbons that can permeate refineries, chemical plants and pipelines. They've also predicted how each gas would alter conductance through the tubes, providing a voltage "footprint" that would identify it. Now the experimentalists must figure out how to mass-produce the nanotube-based devices. And they must deliver a product reliable enough to safeguard the lives of plant operators.

That type of development of a new material can easily take a decade. But if Nanomix—using its modeling and theoretical expertise to shortcut the process—can pull off the trick in the next year or so, it will validate its strategy for nano invention. It will also open the door to a whole world of sensors. For starters, Nanomix should be able to tailor nanotube sensors to sniff out just about any gas, from carbon monoxide to the compounds used in chemical weapons. And the company is sponsoring academic research aimed at tuning nanotubes to sense the biochemical whiffs of disease, measuring insulin levels in diabetics or detecting antigens that indicate infection. Nanotubes are the ultimate sensing platform, asserts Janac. "You don't need more than single-molecule sensitivity, your power consumption is going to be nanowatts, and in terms of size you can't get smaller—at least in the foreseeable future—than a nanotube. We think we're going to revolutionize the sensor business with this architecture."

NOT ONLY IS THE COMPANY RACING TO GET A NANO PRODUCT TO MARKET, IT MUST COMPETE FOR THE TINY POOL OF VENTURE CAPITAL AVAILABLE FOR NANOTECH.

Nano Dollars

But technical challenges are not the only pressures facing Nanomix. Not only is the company racing to get a nano product to market, it must beat the competition to the relatively small pool of venture capital funding available for nanotech startups. Among many experts, excitement over the prospects of nanotechnology may be growing, but the willingness of investors to sink money into highly speculative technologies is not growing nearly as fast. Which means that Nanomix—like a number of other young nanotech companies—must struggle not only to answer daunting scientific questions but simply to survive.

San Francisco-based Alta Partners gave Nanomix seed funding in 2000, and as of last year Nanomix had raised $4.5 million. But since then, additional funds have been hard to find, as venture capitalists have grown cautious following last year's economic crash. "It's been a long slog getting other people to invest," says Alta partner Peter Schwartz.

Ironically, it is exactly the strengths of Nanomix—a strong academic pedigree and theoretical expertise—that can handicap the company in front of potential investors wary of a field where results often sound more like basic research than viable products. And Nanomix's bevy of theorists makes it especially easy to mistake the firm for a basic-research lab.

The pressure has led Nanomix to put a short-term emphasis on product development at the expense of the company's efforts in theoretical physics. But while Cohen may accept the immediate necessity of getting a product out the door in order to win financial backing, he remains committed to his dream: a company that invents and commercializes nano materials by coupling quantum modeling and theory with deft experimentation. It's a dream filled with exotic materials, limited only by the rules of physics and the cleverness of its practitioners.

Like many nanotech researchers, Cohen and his scientific colleagues at Nanomix are convinced that nano materials will have applications not only in sensing and hydrogen storage, but in electronic devices a thousand times smaller than today's silicon transistors—making possible ultrafast, ultrasmall computers. Lilliputian circuits with billions of nano components may still be years in the future, but Nanomix researchers are already thinking of the nano materials that could make them happen. TR

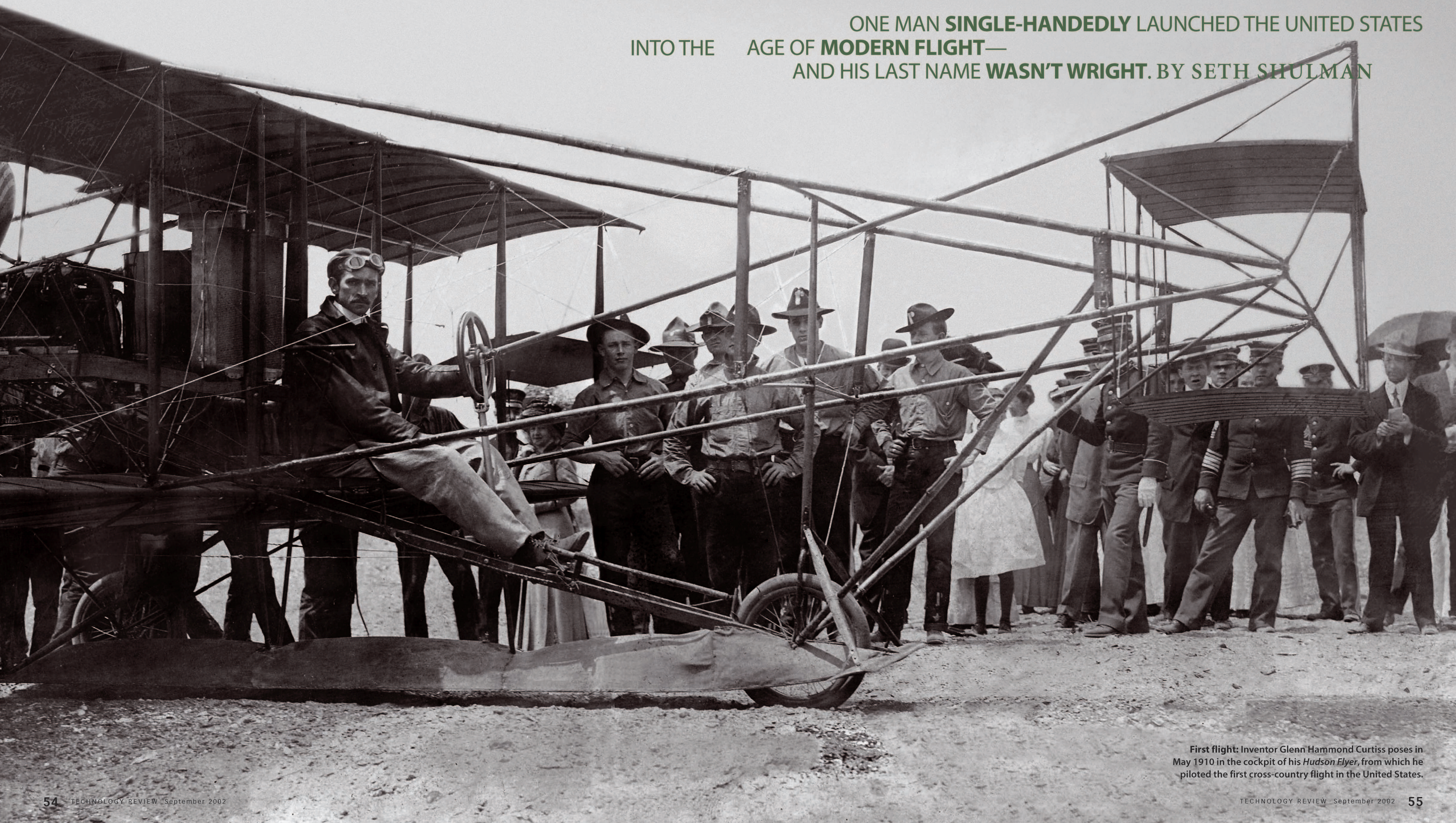
Leaders in Quantum Modeling

GROUP	STRATEGY
Accelrys (San Diego, CA)	Sell models for nano-materials design and to predict the properties of materials such as plastics
Arthur Freeman, Northwestern University (Chicago, IL)	Develop simulation for design of novel materials, including magnetic semiconductors and photovoltaics that convert heat to electricity
William Goddard, Caltech (Pasadena, CA)	Apply models to the design of semiconductors and polymers and to the prediction of protein folding
NASA Ames Research Center (Moffett Field, CA)	Rapidly develop and virtually prototype nanotech components for electronics, computing and sensors
QuesTek (Evanston, IL)	Optimize steel alloys for strength, corrosion resistance and other properties

Product in hand: Nanomix CEO Charles Janac says a gas detection sensor that uses nanotubes will be ready by next year.

THE FLIGHT THAT TAMED THE SKIES

ONE MAN **SINGLE-HANDEDLY** LAUNCHED THE UNITED STATES INTO THE AGE OF **MODERN FLIGHT**— AND HIS LAST NAME **WASN'T WRIGHT**. BY SETH SHULMAN



First flight: Inventor Glenn Hammond Curtiss poses in May 1910 in the cockpit of his *Hudson Flyer*, from which he piloted the first cross-country flight in the United States.

Next year marks the centennial of flight—100 years since the December day in Kitty Hawk, NC, when the Wright brothers etched themselves so deeply into our collective consciousness. No doubt a good deal of hoopla will be whipped up about those two bicycle builders and their flight that changed America. But what the history books leave out is that the highly secretive Wright brothers refused to publicly demonstrate their airplane for four and a half years after that now legendary 12-second, 37-meter hop. By the time they revealed their machine, a number of other inventors already had airplanes flying.

One of them was Glenn Hammond Curtiss, who in the spring of 1910 completed a 243-kilometer public flight along the Hudson River from Albany, NY, to Manhattan. Curtiss's feat—the first true cross-country flight in the United States—was a technological tour de force. Not only was it by far the longest flight yet attempted in the United States, but it meant traveling over unpredictable terrain with virtually unknown wind and weather hazards—quite a different matter from the fair-weather demonstration laps around airfields that characterized most of the previous flights. Hundreds of thousands of people showed up to watch Curtiss's flight, and the *New York Times* devoted no less than six full pages of text and photos to the occasion—the most space the newspaper had ever allotted a single news event.

Glenn Curtiss, largely forgotten today, teaches us an important lesson with implications far beyond aviation history about how technology evolves and how its development is remembered. We're often obsessed with those, like the Wright brothers, who are first to cross a technological threshold. As important as those progenitors are, though, new technologies often take time to find their niches. Determining their ultimate uses—and their markets—is rarely an easy task. It can take daring to demonstrate a new capability that is well beyond the public's imagination. It surely takes dedication, to persevere against the status quo. And it almost always takes vision.

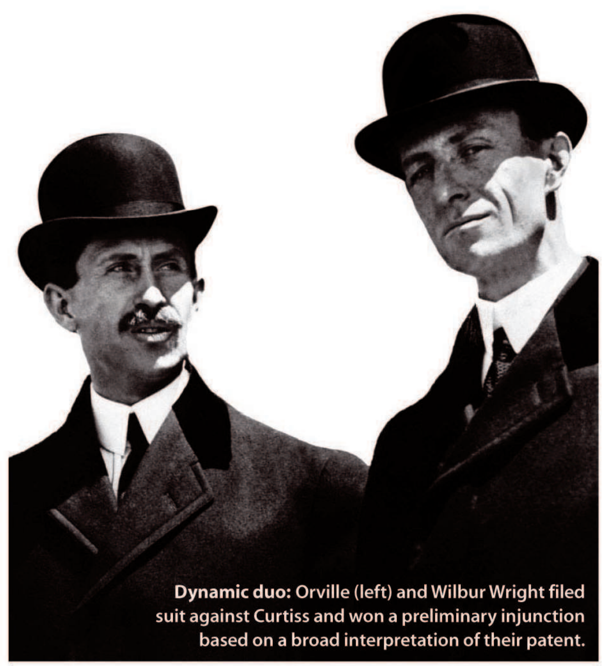
Glenn Curtiss combined all these traits. He arguably did more to make the modern airplane a reality than anyone before or since. While his formal education ended at the eighth grade, Curtiss's mechanical genius resulted in some 500 groundbreaking innovations, including many features still incorporated in airplanes today—from wing flaps to retractable landing gear. (By contrast, none of the Wrights' aeronautical designs have stood the test of time. Most were obsolete by as early as 1912.) But Curtiss's contributions weren't limited to mechanical insights.

By 1910, many flights had already taken place in the United States and in Europe. The year 1909 marked Louis Blériot's astonishing 39.5-kilometer flight across the English Channel and the world's first international air meet, where nearly a dozen airplane designs were on display, and the grand prize was offered for a 20-kilometer flight—twice around a huge, specially designed course marked by pylons several stories tall.

In the United States, Curtiss had been working closely with a team called the Aerial Experiment Association that included Alexander Graham Bell, and on July 4, 1908, he had unveiled his *June Bug* airplane. It made the premiere *public* flight in America, winning *Scientific American*'s coveted prize for the first airplane in the United States to fly a measured kilometer before judges. Later that summer, with all the activity at home and abroad, the Wrights were finally goaded into demonstrating their airplane: Wilbur showed it off to great acclaim in Europe, and Orville demonstrated it to the U.S. military at Fort Myer in Virginia, where it crashed with an army lieutenant on board in the world's first aviation fatality. But despite a growing number of exhibitions before paying spectators, the airplane, like many emerging technologies, was slow to find its place as much more than an exciting novelty.

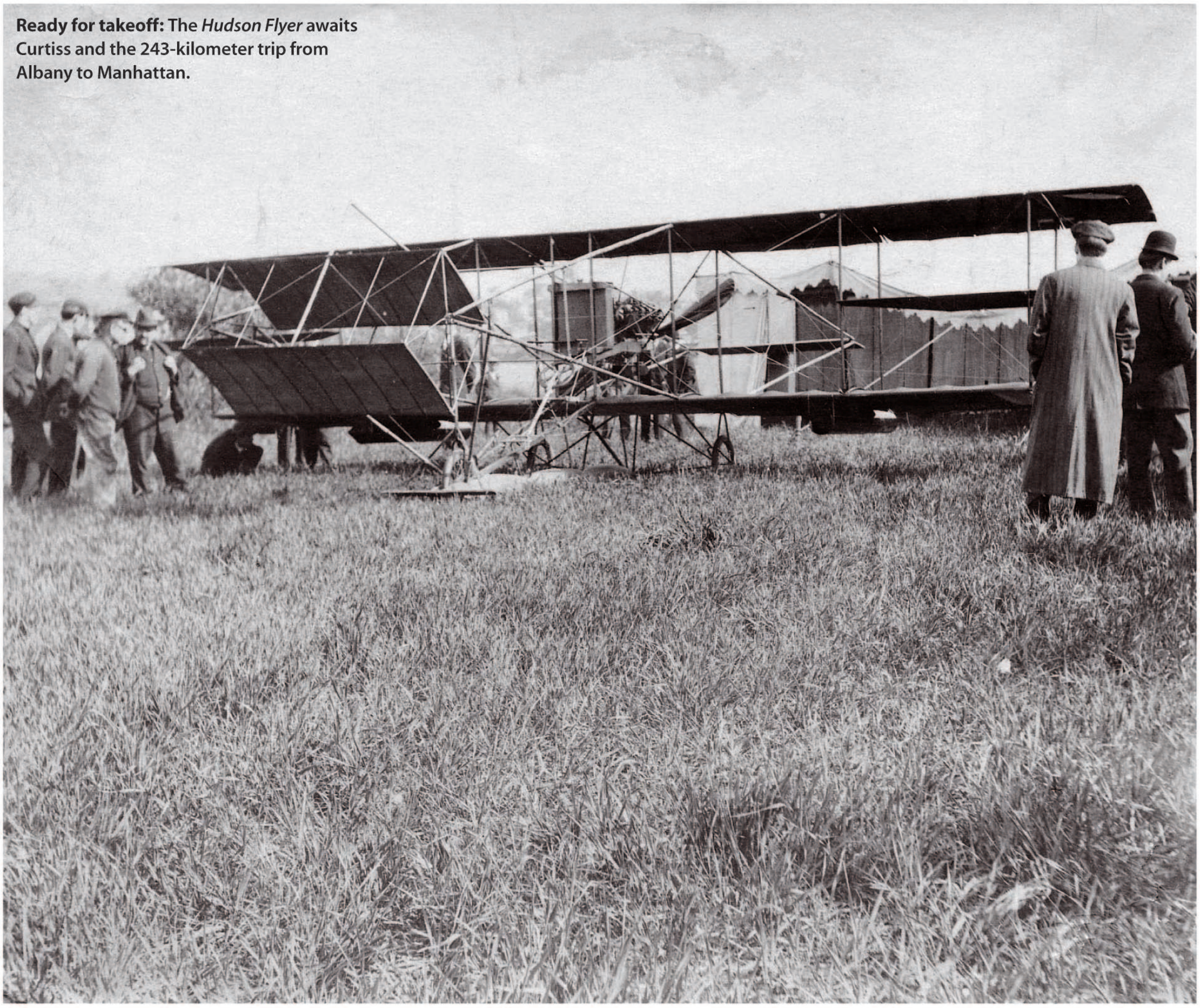
All that changed with Curtiss's 1910 flight. More than any other, that event launched the United States into the age of modern flight, much as Louis Paulhan's similar 1910 flight from London to Manchester did Europe. These two dramatic journeys on either side of the Atlantic cleared the path for the development of airmail and modern air travel, as well as the terrible prospect of air power in war.

Near dawn on May 29, 1910, in a field on Rensselaer Island on the outskirts of Albany, NY, Curtiss donned his flying outfit in a makeshift tent. When he stepped out, he was in a pair of fisherman's rubberized waders that came up to his armpits, a cork life jacket, a snug-fitting cap and a pair of goggles. The waders, Curtiss later explained, were not intended so much for the prospect of a water landing as to provide warmth. After all, despite the clear spring day, Curtiss would be flying in the open, several hundred meters in the air, at a speed of roughly 80 kilometers per hour.



Dynamic duo: Orville (left) and Wilbur Wright filed suit against Curtiss and won a preliminary injunction based on a broad interpretation of their patent.

CORBIS (WRIGHT BROTHERS, CA. 1910); GLENN H. CURTISS MUSEUM (ALL OTHERS)



Ready for takeoff: The *Hudson Flyer* awaits Curtiss and the 243-kilometer trip from Albany to Manhattan.

Even at the early hour, nearly a hundred groggy spectators had assembled at the edge of the field. With virtually no fanfare, Curtiss took the pilot's seat in the airplane—one of a handful of airplanes that he had designed and built. A fabric-covered pusher biplane, it had a large wooden propeller that sat behind a dual set of wings. Because Curtiss would make the entire flight over the Hudson River, he had fitted an airtight metal pontoon beneath each wing and, from cloth used for hot-air balloons, had sewn five small air bags and roped them, inflated, onto the undercarriage of the airplane's frame. The *Hudson Flyer* was thus the world's first "amphibian plane." It could not take off from water (Curtiss would brilliantly solve that problem the following year), but as he and his friend and assistant Henry Kleckler proved in earlier tests, it could handily accomplish a water landing.

From his perch on the makeshift runway, Curtiss noted the direction of the smoke from factory stacks to judge wind direction as he readied for takeoff. In Curtiss's own detailed, minute-by-minute account, published in 1912, he describes rising smoothly from the Albany field to an altitude of 212 meters and flying straight above the middle of the river. With the Hudson spread out below him like a wide, glimmering road, he noticed with fascination that he could see through the clear water to deep beneath the river's surface. Finally airborne on such a beautiful, cloudless day, "I felt an immense sense of relief," Curtiss writes. "The motor sounded like music."

Curtiss had his sights on one of the most tantalizing aviation challenges of the day. Joseph Pulitzer, the wealthy publisher of the *New York World*, had offered a $10,000 prize to the first aviator to fly from Albany to Manhattan. According to the rules, the airplane could make two stops along the route, provided the journey occurred within a 24-hour period. There was no thought of a nonstop flight because no airplane of the period could carry enough fuel to cover such a distance. Pulitzer's contest drew much public attention. The only problem was, most everyone deemed the feat impossible. Nearly a year after Pulitzer's announcement, not one airplane pilot had stepped forward to meet the challenge.

Making things considerably more dramatic for Curtiss were his personal circumstances. In January 1910, a U.S. federal court, in a startlingly broad interpretation of a Wright brothers' patent, had issued a preliminary injunction against Curtiss. As a result, even though the case had yet to be heard, Curtiss was legally prohibited from manufacturing or even exhibiting his aircraft in the United States without a license from the Wrights. And the brothers, who had received backing from a

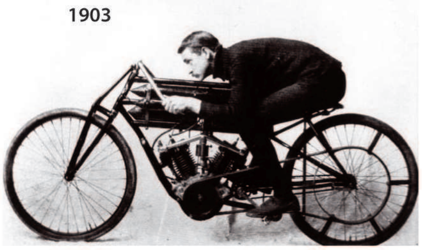
Other Curtiss Firsts

Well before—and after—Glenn Curtiss made his milestone flight from Albany to New York, he was celebrated for a series of breakthroughs.

1903 **American motorcycle champion.** Curtiss won the first championship tournament of the National Cycle Association, in Yonkers, NY, by riding 1.6 kilometers in 56.4 seconds.

1905 **"Fastest man alive."** Curtiss set an unofficial world speed record of 219.4 kilometers per hour at Ormond Beach, FL, with the first V-8 engine motorcycle, which he designed.

1903



1908 **First U.S. public flight.** Curtiss made the first official public flight in the United States on July 4, 1908, in Hammondsport, NY, flying 1,542 meters in the *June Bug*.

1909 **International air speed record.** Curtiss's airplane the *Rheims Racer* set an air speed record of 74.4 kilometers per hour at the world's first International Air Meet in Rheims, France.

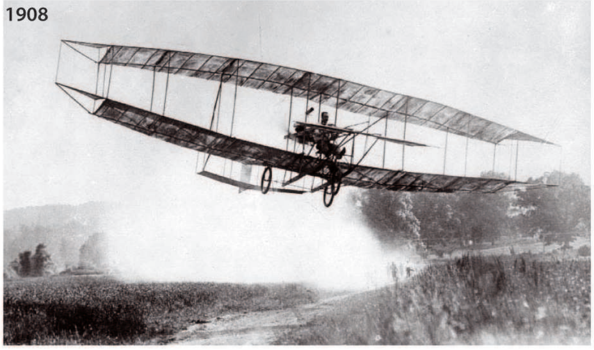
1910 **Ship deck takeoff.** Curtiss designed the first airplane to successfully take off from a naval vessel. It was demonstrated for the U.S. Navy by pilot Eugene Ely.

1911 **Retractable landing gear.** Curtiss designed and built the *Triad*, the first aircraft with retractable landing gear as well as pontoons. It could take off and land from either land or water. In that same year, the Aero Club of America honored him with pilot license number 1.

1914 **Model of the "Jenny."** Curtiss introduced the first model of the JN-1 (nicknamed "Jenny"), the most successful aircraft of its time. Some 6,000 Jennies were eventually built during World War I as key planes for training pilots.

1919 **Transatlantic flight.** The NC-4, a seaplane designed by Curtiss, was the first to successfully cross the Atlantic, eight years before Charles Lindbergh's solo crossing.

1908



consortium that included Cornelius Vanderbilt and came to be known as the Wall Street Air Trust, were in no mood to discuss licensing arrangements—especially with Curtiss.

The Wrights made little secret of the fact that they sought a monopoly on the airplane comparable to the one Alexander Graham Bell had won on the telephone. But the case looks particularly odd in hindsight. The Wrights patented their so-called wing-warping method of bending their airplanes' delicate wings in flight to achieve lateral stability. It was a conceptual breakthrough, but it was hopelessly impractical. Few pilots other than the Wrights were ever able to master it, and many died trying; it quickly became obsolete.

Curtiss never used the Wrights' method. Instead, he and his team developed ailerons: flaps appended to stronger, rigid wings. As Curtiss argued, the ailerons represented a separate and distinct system for achieving lateral stability—not to mention one that would quickly become the industry standard.

With the help of his friend and advisor Judge Monroe Wheeler, Curtiss managed to get the court to allow him to post a $10,000 bond and resume aviation work while he appealed the U.S. court's injunction. The money, in essence, served as an advance on royalties due to the Wrights in the event that Curtiss lost the case. Curtiss posted the bond, but he was forced several times to pay his employees out of his own deflating pocket. Even worse, given his precarious legal situation, he didn't know where he could turn for a loan, and his company, based in his hometown of Hammondsport, NY, had been officially forced into bankruptcy in April 1910.

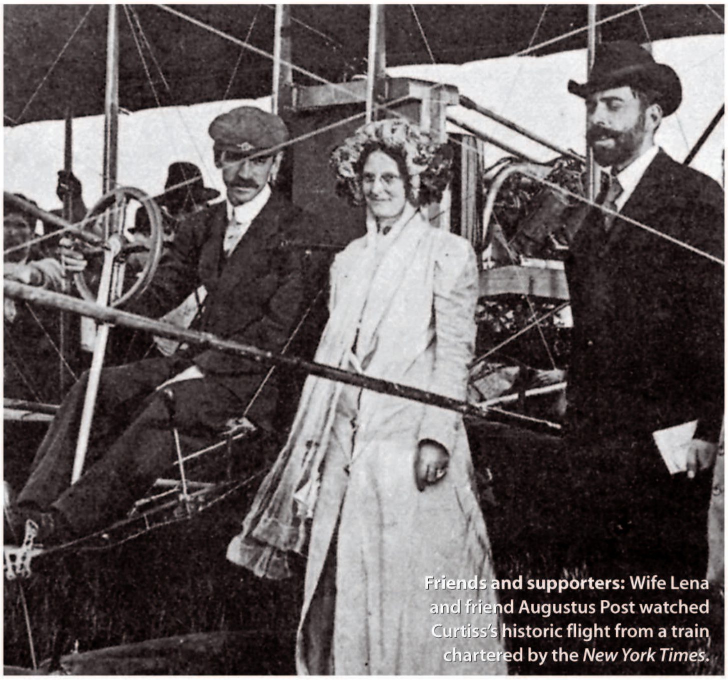
It was at this dire point in his career that Curtiss seized upon the Albany-Manhattan flight—impossible or not—as one of the very few promising options he had. Curtiss's closest advisors, and his wife Lena (who had always supported his dangerous forays into aviation before), were united in judging the flight to be too risky to attempt. But in signature fashion, Curtiss, undeterred, was a juggernaut of action even as those closest to him remained skeptical. He came to see the flight as a kind of redemptive project—a way to somehow persevere against all odds.

In May, word of Curtiss's intended flight sparked headlines. The *New York World* launched an immediate publicity campaign for the flight. Not to be outdone, the rival *New York Times* announced a coup: it would charter a special train on the New York Central's Hudson River Line to pace the flight, carrying Lena Curtiss and other members of the Curtiss team. Much to the dismay of the staff at the *World*, the train would also carry *New York Times* reporters and photographers, affording them an exclusive opportunity to keep abreast of the plane every step of the way.

They would only lose sight of him twice as he stopped to refuel, a challenge Curtiss planned for in advance by reconnoitering suitable landing sites along the route. Among the places he visited were the large, open grounds of the State Hospital for the Insane perched high on a hill above Poughkeepsie. The superintendent, Dr. Taylor, was his escort. As Curtiss later remembered, the doctor chuckled "when I told him that I intended stopping there on my way down the river in a flying machine."

"Sure you can land here," Dr. Taylor said. "Most of you flying-machine inventors end up here anyway."

On the first leg of the flight, high above the Hudson River, Curtiss veered to fly alongside the tracking train chartered by the *New York Times*. He could see his wife Lena waving her handkerchief and later a large American flag out the train window. Henry Kleckler, too, popped in and out of the train window, nervously flapping his cap. Train and airplane, both traveling at roughly 80 kilometers an hour, wove together and apart along the voyage. As Curtiss remembered, "It was like a real race, and I enjoyed the contest more than anything else during the flight."



Friends and supporters: Wife Lena and friend Augustus Post watched Curtiss's historic flight from a train chartered by the *New York Times*.

With little instrumentation, Curtiss had no way to determine his speed other than the strength of the wind against his face. With no altimeter, he could similarly only guess at his altitude. And the deafening drone of the engine behind his head shut out all other sound. Nonetheless, he felt in complete control of the airplane and intensely alert to the tiniest details around him on the crystalline day. Below him, groups of people stared from the riverbanks and waved from boats; the captain of a river tugboat tooted its horn. Although Curtiss couldn't hear it, he saw the blast of white steam rise eerily silent into the air below him.

It was clear sailing until his first stop in an open field just past Poughkeepsie, almost 140 kilometers into his journey, where he greeted assembled spectators and, despite his careful planning, wound up having to borrow gas and oil from generous motorists to get airborne again. Curtiss was soon back above the Hudson. But trouble lay ahead.

THE WRIGHTS MADE LITTLE SECRET OF THE FACT THAT THEY SOUGHT A MONOPOLY ON THE AIRPLANE COMPARABLE TO THE ONE BELL HAD WON ON THE TELEPHONE.

Thirty-two kilometers south of Poughkeepsie, the river carves a steep 24-kilometer-long gorge near Storm King Mountain and Breakneck Ridge. The spot funnels treacherous wind currents up from the river. Aware of the danger from his research and reconnaissance, Curtiss tried to climb above it, rising to an altitude of roughly 600 meters. But it was not high enough. Just past Storm King Mountain, as Lena watched frantic and helpless from the train, a crosscurrent tilted the plane sideways, and it dropped more than 30 meters within seconds. Momentarily losing control, Curtiss was nearly thrown from the airplane. "It was the worst plunge I ever got in an aeroplane," Curtiss said later. "My heart was in my mouth. I thought it was all over."

As the wind steadied, Curtiss managed to regain control of his airplane. Ahead, he could just make out the northern tip of Manhattan and the outline of the 50-story-high Metropolitan Life Tower—the world's tallest building—above the line of the horizon. He was beginning to feel elated with the knowledge that he was so near the end of the trip when he noticed that his oil gauge read near empty. The design of the plane required Curtiss to lubricate the engine through a manual control roughly every ten minutes to assure its smooth running; his first thought was that he must have inadvertently "been too enthusiastic" with the oil lever over Breakneck Ridge. In fact, although he wouldn't discover it until later, the airplane had been seriously leaking oil for some time. With the prospect that his engine could freeze up at any time, Curtiss knew he must land immediately to replenish his oil.

Nervously winging east at the northernmost tip of Manhattan, where the Harlem River curves around at the Harlem Gorge to meet the Hudson, Curtiss looked for a little meadow—one of many such spots he had chosen as possible landing sites. There was no time to lose. Spotting nothing more suitable, he set down on a sloping lawn that rose 30 meters above the Hudson. Safely on the ground, he breathed a sigh of relief and realized that he was inside the city limits. In just over two and a half hours of flying time, he had covered 243 kilometers, averaging nearly 88 kilometers per hour.

Curtiss soon learned that he had landed on the grounds of the estate of the late financier and leather merchant William B. Isham. The current residents, Isham's daughter and her husband, jumped up from reading the Sunday newspaper and ran outside when they heard the roar of the approaching motor. They had just been reading about the proposed flight and were stunned to see Curtiss's airplane bouncing up their sloping front lawn.

At the Isham estate, Curtiss telephoned the *New York World* with the news that he had landed within the city limits. Having technically fulfilled the contest's requirements, another aviator might have pronounced the flight complete. But not Curtiss. He explained that he would continue to his planned landing on Governors Island at the other end of Manhattan as soon as he refilled his oil pan. He said later that he thought of all the spec-

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tators in the city counting on his arrival. Later, one magazine writer noted that Curtiss's decision to fly on over Manhattan was "a magnificent sportsmanlike thing that won him the unbounded admiration of all New York."

After a dangerous and tricky takeoff down the sloping cliff over the river, Curtiss once again rose above the Hudson, this time with the shimmering Manhattan skyline beckoning him onward through the clear midday sky. As he approached the city, he was overwhelmed by the spectacle he saw below him. Crowds were everywhere: on rooftops, in trees and packed many deep along the riverbanks. Passengers on ferry boats and ocean liners craned over railings and waved wildly in the air to him. And people directly beneath him on scores of crafts large and small dotting the Hudson cheered him on. In no time, the Statue of Liberty—Curtiss's sought-after landmark of the finish line—stood close before him. Turning westward, he remembered, he triumphantly "circled the lady with the torch" and headed as planned for the parade grounds at nearby Governors Island.

CURTISS'S FLIGHT BROKE A BARRIER FOR AVIATION. THE AIRPLANE ALL AT ONCE PRESENTED ITSELF AS A USEFUL AND PRACTICAL TECHNOLOGY.

It was just past noon when, after a perfect landing, Curtiss emerged from his airplane to cheers from scores of enthusiastic U.S. Army personnel stationed at the island's small base. Much acclaim followed Curtiss's heroic flight, including awards, dinners and press conferences. The New York press crowned Curtiss "King of the Air." At a black-tie dinner at the Astor Hotel in his honor, Curtiss formally presented to New York mayor William Gaynor a letter given to him by James B. McEwan, the mayor of Albany. It was the first airmail letter delivered in the United States.

Although he was unable to attend the gala event, President William H. Taft sent a congratulatory telegram to Curtiss. "It seems that the wonders of aviation will never cease," Taft wrote, adding that Curtiss's flight "will live long in our memories as having been the greatest."

Taft didn't know the half of it. Curtiss's flight from Albany to New York City broke a formidable psychological barrier for aviation in America. That Sunday, and not just for the hundreds of thousands of witnesses but for many others who read or heard of Curtiss's accomplishment, the airplane all at once presented itself as a useful and practical technology.

The prevailing mythology about the airplane portrays the Wright brothers as earnest young bicycle builders—which they were, early in their careers. But once competition like Curtiss's comes into the picture, the Wrights look more like greedy spoilers. And the astounding leap into the air they took at Kitty Hawk begins to seem less like an isolated breakthrough and more like an important step in a very long progression of brilliant accomplishments in aviation.

The period of the airplane's earliest development, the first decades of the 1900s, was one of dynamism—a time much like today, dominated by fast-paced and unsettling technological change and the clamor to control it. Having made a tremendous breakthrough in aviation, Wilbur and Orville Wright tried to control the development of the airplane in its first decade through patents and aggressive business tactics. Curtiss's legal battle with the Wrights would continue for nine long years—years that were absolutely crucial to the airplane's development. Ultimately, the Wrights would fail in their effort to secure a monopoly, thanks to Curtiss's persistence and, with the advent of World War I, a decision by the U.S. government that forced the Wright Company to cross-license its technology to produce more airplanes for the war.

For his part, Glenn Curtiss did receive a number of patents over his lifetime. But he always permitted further use of the principles underlying his inventions—a strategy that enormously benefited the emerging industry. Unlike the Wrights, Curtiss believed his inventions and products had to succeed or fail in the marketplace on their own merit. The goal, he said, ought to be simply to keep building better airplanes than anyone else. This, ultimately, is the way he would have wanted his career to be judged, and it is how it should be judged: by the lasting, unrivaled success of his aeronautical inventions. TR

"The Flight That Tamed the Skies" is adapted from Seth Shulman's new book Unlocking the Sky: Glenn Hammond Curtiss and the Race to Invent the Airplane, *due out this fall from HarperCollins.*


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RENOWNED NUCLEAR PHYSICIST AND LONGTIME PRESIDENTIAL ADVISOR **RICHARD L. GARWIN** TAKES A COLD HARD LOOK AT THE TERRORIST THREATS WE STILL FACE.

THE TECHNOLOGY OF MEGATERROR

ILLUSTRATIONS BY MATT MAHURIN

THE LOSS OF MORE THAN 3,000 PEOPLE TO AL-QAEDA TERrorism on September 11, 2001, brought to many Americans the sudden recognition that their country was no longer leading a charmed life. But a number of the nation's security experts had seen it coming. In 1999, for example, a commission led by Senators Gary Hart and Warren B. Rudman examined U.S. security policies and, in a report published two years before the al-Qaeda attack, concluded, "There will...be a greater probability of [catastrophic terrorism] in the next millennium....Future terrorists will probably be even less hierarchically organized, and yet better networked, than they are today. Their diffuse nature will make them more anonymous, yet their ability to coordinate mass effects on a global basis will increase....The United States should assume that it will be a target of terrorist attacks against its homeland using weapons of mass destruction. The United States *will be vulnerable to such strikes*."

The concept of megaterrorism was well known. The warning was there. Only the date, place and nature of the deed were in question to those who had looked at the prospects. And though last September's slaughter was not caused by the "weapons of mass destruction" of which the Hart-Rudman Commission warned, it is still my belief that the biggest threats we face are two types of such weapons: biological and nuclear devices.

I am, unfortunately, no stranger to either. My work on nuclear weaponry began at the Los Alamos National Laboratory in 1950 and continues to this day. Through many years of service on the White House President's Science Advisory Committee and its many panels, and with similar bodies of the U.S. Defense Department and the U.S. Department of State, I have become familiar with the status of nuclear weapons around the world. And in 1998 I served with Donald Rumsfeld, now the secretary of defense, and seven others on the Commission to Assess the Ballistic Missile Threat to the United States, which by law had access to all intelligence regarding not only foreign missiles and nuclear weaponry but bioweapons as well.

BIOLOGICAL-WARFARE AGENTS ARE, IN MY JUDGMENT, THE biggest menace we currently face, but not all such agents are created equal. Bioweapons perfected by the major powers in the immediate postwar period included diseases of plants, animals and humans. They were further divided into diseases such as anthrax that are merely infectious—caused only through direct exposure to a weaponized bacterium or virus—and those like smallpox that are also contagious, or spread from one person to another.

The five deaths and six inhalational anthrax illnesses caused by anthrax-bearing letters—probably from a single domestic terrorist incited by the events of September 11—have taught us a lot about inhalation anthrax that we did not know before. Quite apparent, and not surprising, is the fact that the spores may reside for weeks and months in the lung before vegetating—even in the presence of effective antibiotics—and if antibiotics are withdrawn, an ensuing infection is usually lethal within days unless promptly treated. The likelihood of prompt treatment has, of course, increased greatly, since a disease almost unknown to the ordinary medical practitioner is now at the top of everybody's alert list. Yet anthrax remains a concern because in the form of spores it is so durable. The dissemination of dry spores has been achieved in Russia and the United States and perhaps elsewhere, and tons of anthrax spores have been produced and weaponized—for instance, in 1991 in Iraq.

But my chief concern is not a handful of anthrax letters, or even a hypothetical mass mailing of 10,000 anthrax letters. What worries me most are biological agents that are contagious as well as infectious.

Take smallpox, for example, a viral disease that spreads rapidly and kills 30 percent or more of the people it infects. Through foresight and aggressive action on the part of the World Health Organization, smallpox was deemed eradicated in 1980. Two stocks of smallpox were officially maintained—one in the United States and one in what is now Russia—but testimony from one of the workers in the Russian biowarfare program attests that the Soviet Union had secretly weaponized smallpox. The Soviets apparently had

numerous ballistic-missile warheads filled with biowarfare agents; some of those agents may have been stolen or diverted. Since the United States has never had access to Russia's former military biowarfare installations, we just don't know the full extent of the program and the degree to which agents remained under the government's control.

It is also likely that some individual researchers in the United States and elsewhere, whether in military or civil programs, did not destroy their stocks of smallpox virus when their nations signed the Biological Warfare Convention of 1972 but kept some for a rainy day—perhaps without any malevolent intent. Some of these stocks may have fallen into the hands of terrorist groups; stored, they could be multiplied by the same techniques used to grow viruses for human or animal vaccines and could be available for widespread dispersion from moving cars or trucks. Depending upon the planning and organization for countering such an attack, the initial infection of 100,000 people might lead to infection of many tens of millions and, given the smallpox fatality rate, the death of 30 million people within four months.

Against smallpox, as with most other viruses, antibiotics are useless; there is no effective treatment after symptoms appear. There is, however, an effective vaccine. But though it was long mandatory in the United States, smallpox vaccination was abandoned here in 1972. At the time I argued strongly in the President's Science Advisory Committee that the country would be too vulnerable to intentional attack, and that vaccination should be continued, despite the two or three people per year who might die from vaccine side effects. The government didn't heed this urging, but it preserved in liquid nitrogen a stock of about 15 million doses of the smallpox vaccine.

By conventional wisdom, this stockpile is not enough to vaccinate the entire U.S. population. But recent experiments have shown that the vaccine is effective in doses five times as dilute as normal, and a further economy may be achieved by adjustment to the way the vaccine is delivered. What's more, in late March 2002, vaccine maker Aventis Pasteur announced that it had some 85 million additional doses of smallpox vaccine in storage and agreed to donate them to the U.S. government; these also can be extended by dilution. In other words, there is now more than enough for every U.S. resident (though the government has not, so far, reinstated widespread vaccination), even without the new smallpox vaccine currently in development.

In the case of smallpox we got lucky. But there are many potential biowarfare agents, such as *Burkholderia mallei*, a contagious bacterium that causes a deadly disease called glanders, for which there is no vaccine. They might be disseminated within large buildings—and distributed by the circulating air in heating, ventilating and air-conditioning systems—or outdoors, to expose whole cities. And in the case of an outside release, even people who were indoors with the windows shut would be at risk of exposure, as air tends to leak through tiny gaps and cracks in most buildings.

Simply replacing the normal air filters used in most ventilation systems with high-efficiency filters—which are already widely available—could offer some degree of protection against a number of bioweapons. Such filters aren't a perfect solution, though, because contaminated air still circulates for a time before getting routed through the filter. But if living and working spaces were maintained at positive pressure so that any leaked air flowed out instead of in, high-efficiency filtration of "makeup air"—that required to maintain the positive pressure—could reduce the risk of bioweapon exposure by a factor of a thousand or more.

I strongly advocate such positive-pressure protection. It could be applied not only in buildings but in public transport or even private automobiles as well. And implementing it is relatively cheap. At a typical annual office rental rate of about $9,000 per employee, it amounts to an added cost of about $9 per employee each year—a burden many judge is overwhelmed by its routine benefits in reducing allergies and normal transmission of communicable diseases.

Some argue against filtration and positive-pressure protection because they offer imperfect solutions—they don't protect people who are outside, and they don't protect against toxic chemicals. The demand for perfection often stands in the way of tremendous benefit.

MUCH AS THE ANTHRAX LETTERS FOCUSED THE NATION'S attention on the threat of bioterrorism, the arrest in May of Jose Padilla threw a spotlight on another threat: "radiological dispersal devices," or more colloquially, "dirty bombs."

Such devices use explosives or other means to disperse solid or liquid radioactive materials. And there are numerous potential sources of radioactive materials. Rods of cobalt-60, for example, are used for irradiating spices and other foods to kill insects and germs, for medical radiation therapy to treat cancer and for industrial radiography to x-ray thick and dense materials. Strontium-90 provides heat for powering isolated instruments or radio relays. But for the most part, a dirty bomb poses little more immediate health threat than a conventional bomb.

MY CHIEF CONCERN IS NOT A HANDFUL OF ANTHRAX LETTERS, OR EVEN 10,000 OF THEM. WHAT WORRIES ME MOST ARE BIOLOGICAL AGENTS THAT ARE CONTAGIOUS.

Consider, for example, a hypothetical attack on Munich with one kilogram of plutonium dispersed by high explosives. Assuming a very pessimistic low wind speed so that the radioactive cloud remains over the city for 12 hours, the net result is that—after 40 years or so—120 people would die of cancer caused by the plutonium. The economic ramifications of a detonated dirty bomb, on the other hand, could be tremendous, as a very large area of contamination would have to be evacuated and cleaned up or left uninhabited for years.

Nuclear explosives, however, represent a much larger threat. A terrorist nuclear explosive would devastate a city, whether detonated in the hold of a ship in harbor, in a cargo container, in a cellar, or in an apartment. U.S. and Russian strategic nuclear weapons are built to yield explosions in the range

ally provided with substantial protection against unauthorized detonation, and considerable skill would be required to bypass this protection. An improvised nuclear device would not have this problem but would require the acquisition of one essential ingredient—fissile material, either plutonium or highly enriched uranium.

Fissile material is not an article of commerce and itself would have to be stolen or diverted. The first plutonium bomb incorporated six kilograms of weapons-grade plutonium, of which more than 250 tons has now been made—enough for 40,000 such crude weapons. In addition, every large nuclear power reactor produces annually on the order of 200 kilograms of plutonium, which is not weapons grade and need not be to make an improvised nuclear device. Indeed, there are 100 tons or more of plutonium accumulated in Japan, France and the United Kingdom alone from the reprocessing of civilian power reactor fuel.

The low-enriched uranium used in U.S. nuclear reactors, on the other hand, can in no way be used directly to make a nuclear explosive. But highly enriched uranium as used in nuclear weaponry is also employed in some research reactors and in fuel for naval reactors, such as those that propel our aircraft carriers and submarines. Likewise, Russian nuclear-propelled ships use highly enriched uranium. And in Russia particularly, stocks of highly enriched uranium and plutonium (even weapons-grade plutonium) intended as nuclear fuel do not have nearly the security provided to nuclear weaponry.

of 150 kilotons, or the equivalent of 150,000 tons of TNT. But even if a terrorist set off a device that caused just a one-kiloton explosion, the effect on a city like Manhattan would be devastating. Eleven city blocks would be obliterated. People in a 53-block area would be killed outright by the heat of the explosion. Those in an 88-block area would immediately receive a lethal dose of radiation. During working hours in a densely populated part of Manhattan with some 2,400 people per block, some 210,000 people would die. For a 10-kiloton explosion, perhaps five times as many would die.

Hospitals would be overwhelmed by the number of people injured by flying glass, suffering from radiation exposure and the like. Transit and communications would be severely crippled. Organized medicine would be unable to cope. Even after the initial crisis had passed, public-safety personnel would face the daunting task of determining where high levels of radioactivity had rendered areas uninhabitable, and where contamination was slight enough that people could return to their homes.

How could such a terrorist explosion come about? Military nuclear weapons could be stolen or diverted, but they are usu-

The best single protection against the terrorist use of nuclear weapons is to block the acquisition of plutonium or enriched uranium. After some months of denigrating U.S. programs that have existed since 1994 to help Russia protect weapon-usable materials, the Bush administration in December 2001 recognized the seriousness of this problem and that something can be done to solve it, and it has increased the budget for such "cooperative threat-reduction activities." In a separate deal, the United States is buying 500 tons of highly enriched uranium (diluted in Russia to low-enriched uranium to fuel U.S. reactors) over 20 years, at a cost of about $12 billion. Once diluted, this material is useless for the manufacture of nuclear weapons. But the delivery of the nuclear fuel will not be complete until 2014, and Russia had diluted only about 150 tons of highly enriched uranium by summer 2002. Here is a threat that will persist for much longer than necessary. This is a serious concern. Every 100 tons of bomb uranium can be used to build more than 1,000 nuclear weapons of the type that destroyed Hiroshima.

It would be a simple matter for the United States and/or the international community to advance Russia the much smaller amount of money required to blend down the remaining 350 tons (and perhaps another 700 tons not included in this deal) enough to render it unusable for nuclear weaponry. This could be done in about two years, and the money would be repaid by Russia with or without interest when this material was further blended and transferred to the United States.

Eliminating such large stores of weaponable materials is one important step. Detecting the illegal transport of such materials when they fall into the wrong hands is another. Can weapon-usable materials be detected in transit? Yes and no. Radiation detectors sensitive to low-energy gamma rays from plutonium are routinely deployed at the portals of plants processing plutonium. Plutonium detection can be foiled by the use of enough lead shielding, but that eliminates the possibility of accumulating a weapon mass of plutonium by routinely smuggling tiny amounts through a portal, since the shield would be too massive to conceal on the body. Uranium, however, is somewhat more difficult to detect than plutonium.

In the late 1940s and early 1950s, the threat of a Soviet nuclear weapon smuggled into the United States was taken seriously. As recounted in a recent *Washington Post* op-ed piece, J. Robert Oppenheimer, who led the Los Alamos effort to produce the nuclear weapons used in 1945, was asked in 1946 at a congressional hearing "whether three or four men couldn't smuggle units of an [atomic] bomb into New York and blow up the whole city." His reply: "Of course it could be done, and people could destroy New York." Asked how such a weapon smuggled in a crate could be detected, Oppenheimer replied, "With a screwdriver." Some years later the U.S. Atomic Energy Commission published a still classified study, the "Screwdriver Report."

Currently, the United States has dedicated nuclear-emergency search teams with the ability to deploy about 600 people with devices to detect and disable nuclear weapons in the case of a credible bomb threat. But a terrorist with a mission to actually kill people would certainly not alert the authorities to the existence of a nuclear explosive; the device would need to be detected either in transit, following intelligence tips or by generalized search. This is a tall order for the nuclear-emergency search team, even granting substantial improvement in its capabilities. We must—and with proper research we can—develop improved sensing technology capable of detecting even shielded nuclear materials in cargo containers, trucks, luggage and so forth. Deployed widely, such technology would be the embodiment of Oppenheimer's screwdriver.

IF WE TAKE THE RIGHT MEASURES, WE CAN REDUCE THE LIKELIHOOD AND THE IMPACT OF TERRORISM THAT USES BIOLOGICAL AGENTS AND **NUCLEAR EXPLOSIONS**.

THESE ARE FRIGHTENING TIMES, BUT WE CAN REDUCE THE likelihood and the impact of terrorism that uses bioagents and nuclear explosions. Against bioterrorism, the most feasible and urgent remedy is one that does not depend upon the details of the threat: the deployment in homes and offices of filtration and positive-pressure protection systems. That, in addition to masks, education on personal hygiene and contingency plans, can essentially eliminate what could otherwise be devastating epidemics caused by contagious bioagents. In the longer run, the war against bioterrorism would benefit from the development and production of vaccines—not only in the United States, but abroad—and the development of antitoxins and other treatments.

To protect against radiological dispersal devices, we should improve the security of radioactive sources used in industry and the health sector. And since such devices for the most part pose limited immediate harm but constitute a serious economic threat and can lead to panic, we should have contingency plans and public-education programs that forestall precipitous and dangerous movements among people who face no significant short-term hazards. Against the terrible threat of destruction by a smuggled nuclear weapon or an improvised nuclear explosive, much more must be done to secure at their source the materials indispensable to such devices—plutonium and highly enriched uranium.

Still, even these feasible partial remedies will not be in place when they are needed unless the United States creates a technical organization with responsibility for evaluating the terrorist threat, prescribing remedies and evaluating how we are doing at implementing them. This needs to be done with wartime urgency, the same urgency that drove the creation during World War II of the radar lab at MIT and of the Manhattan Project. For the most part, however, the work of this new laboratory would not need to be so highly classified. It could begin simply by carving out sections of a small number of existing government or national laboratories and putting them under the firm control of a homeland-defense analogue of J. Robert Oppenheimer—a person with technical leadership and total dedication to the cause of reducing the vulnerability of our society.

Indeed, a homeland security institute is one of the major recommendations of the National Academies' Committee on Science and Technology for Countering Terrorism, in a report released on June 25, 2002. I served on that committee and on its panel on nuclear and radiological issues. The proposed Department of Homeland Security (perhaps headed by a 21st-century counterpart to General Leslie R. Groves of Manhattan Project fame) can in principle realize some of the near-term remedies I have advocated. It could also mount a longer-term research and development program to reduce the likelihood of catastrophic terrorism and—in the case of bioweapons and radiological dispersal devices—to reduce the economic and human costs in the event of an actual attack. The solution is not simply more organization but letting competent people do their jobs. TR

Richard L. Garwin is a senior fellow for science and technology at the Council on Foreign Relations and an IBM fellow emeritus.


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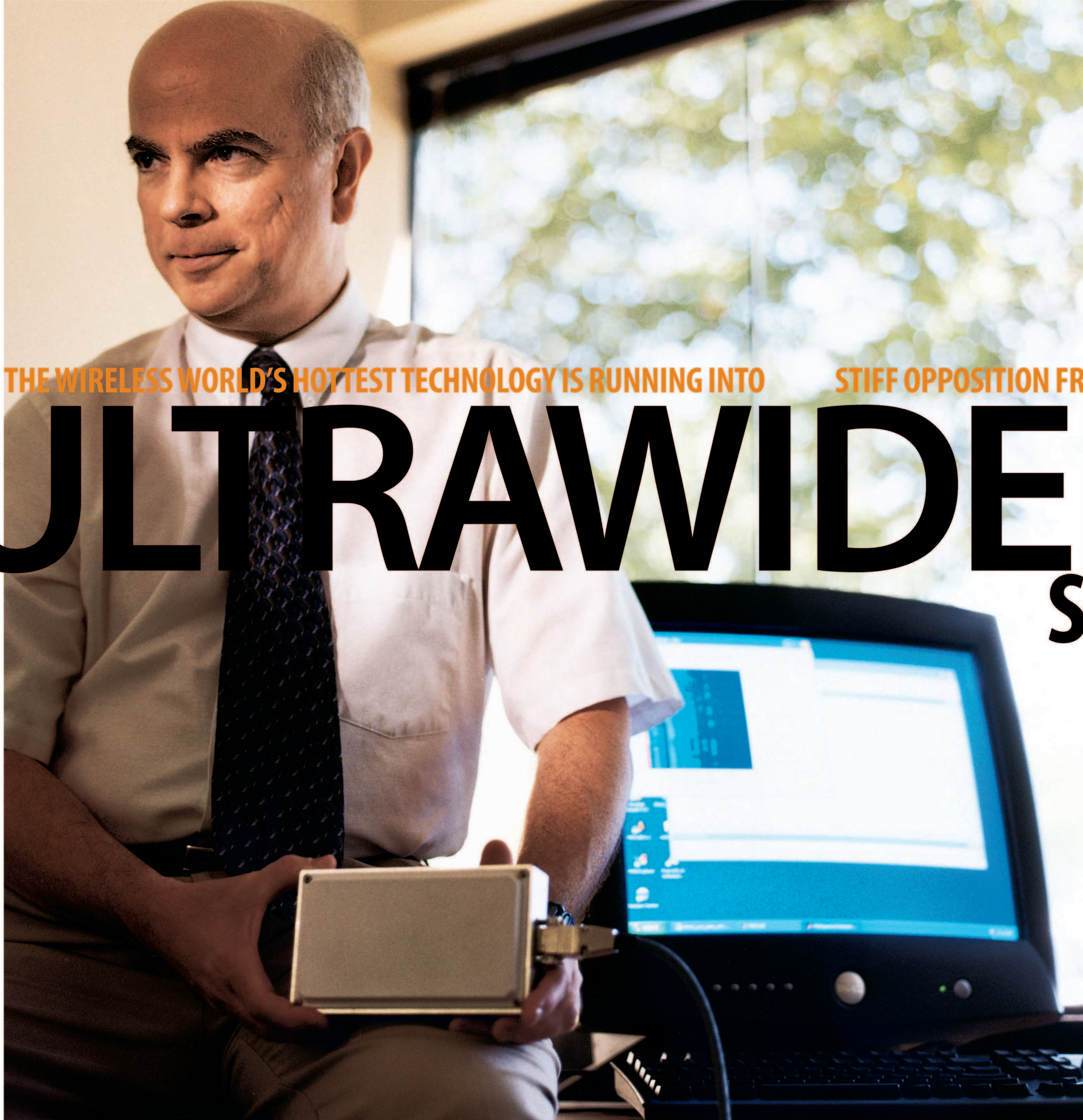


Penetrating vision: Robert Fontana, president of Multispectral Solutions, shows off an ultrawideband radar that can track objects through walls and other obstacles.
PHOTOGRAPH BY CHRIS HARTLOVE

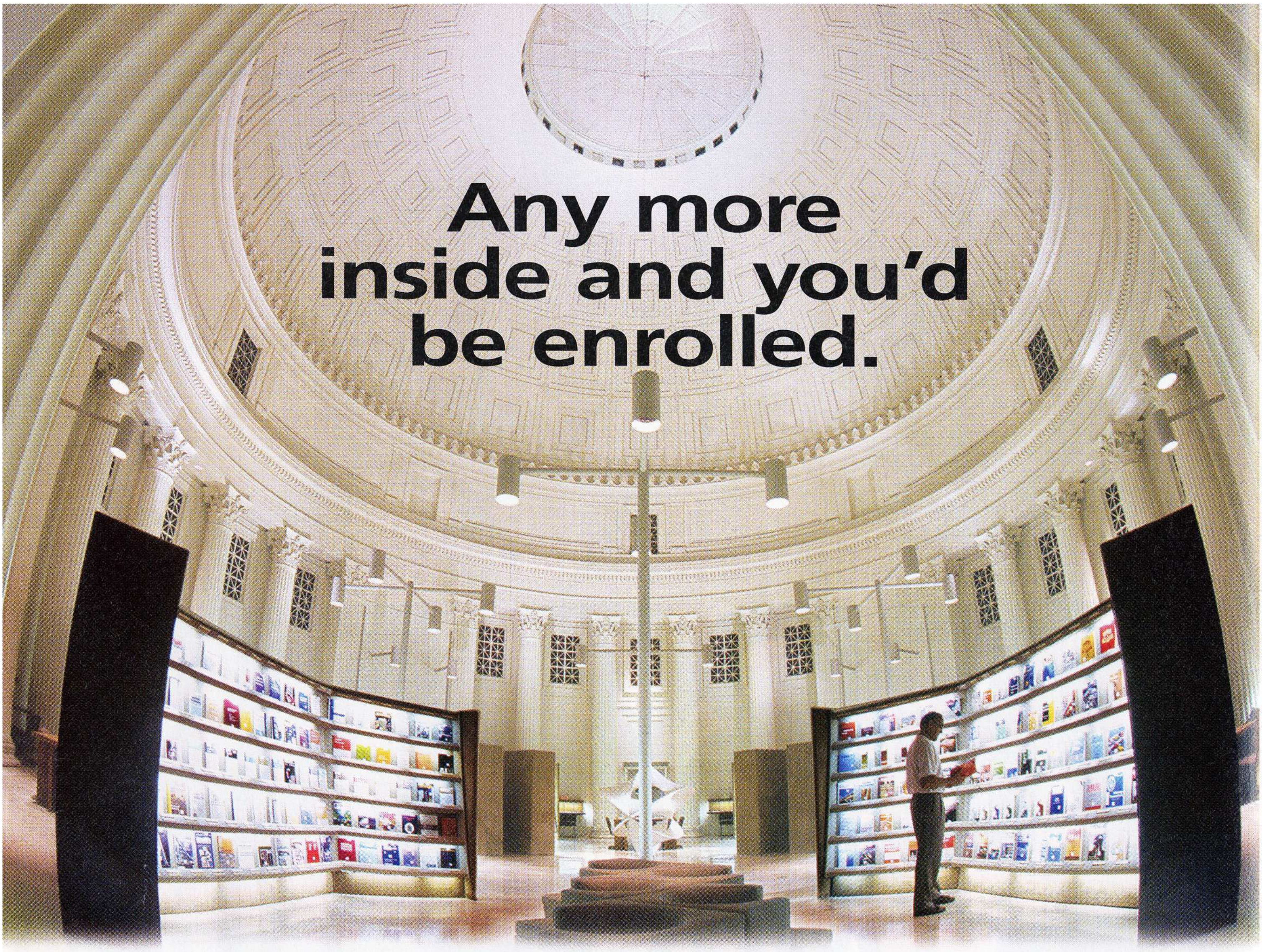
THE WIRELESS WORLD'S HOTTEST TECHNOLOGY IS RUNNING INTO STIFF OPPOSITION FROM THOSE WHO SEE INTERFERENCE AHEAD.

ULTRAWIDEBAND squeezes in

BY ERIKA JONIETZ

Robert Fontana disappears into a hallway. Seconds later, a small reddish blob of pixels appears and moves around a field of blue and green on a computer monitor hooked up to a shoebox-sized device. The splotch tracks Fontana's position in the building, even through the two walls between him and the technology he's showing off: a tracking and collision avoidance system that can "see" through barriers like walls (or trees) and measure a target's position, bearing and speed. Fontana, president of Germantown, MD-based Multispectral Solutions, says what's inside his shoebox can one day help keep helicopters, cars and other vehicles from ramming into obstacles like power lines or people.

Behind the device is a radio technology called ultrawideband that for decades was the province of military labs. But in the last few years, start-ups, information technology companies and consumer electronics giants have begun pushing ultrawideband beyond the radarlike systems the military pioneered and into applications that could transform the home. Sony and newcomer XtremeSpectrum in Vienna, VA, for instance, are both pursuing the possibility of using ultrawideband transmission to wirelessly link DVD players, stereos and TVs in home entertainment systems.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be enrolled.

In the future, ultrawideband links could distribute extremely information-rich content, endowing a home or office with high-resolution 3-D virtual-reality simulation. Ultrawideband can also zap data between computing devices up to 10 times faster than today's rat's nests of wired links.

Other potential applications include tracking objects and people to centimeter accuracy (even through walls) and ultrasensitive detectors for everything from home security systems to virtual pet enclosures. Ultrawideband tags could let robotic lawn mowers or vacuum cleaners go about their tasks without ever hitting a tree or a sofa. "We've got the most feasible technology for the George Jetson-like homes of the future," says Bruce Watkins, president of Pulse-Link, an ultrawideband startup in San Diego.

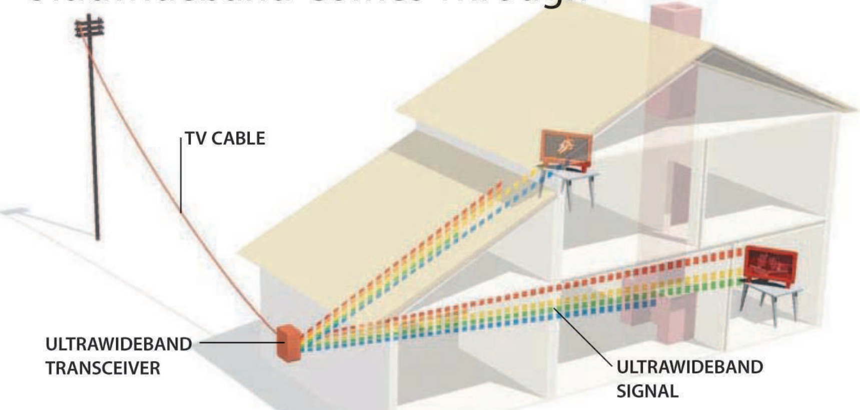
Ultrawideband, proponents say, will deliver all of this via cheap, low-power radios. And, they contend—albeit over vigorous disagreement from skeptics—it won't suffer from the interference problems that plague many existing wireless devices. "It's a tremendous new technology," says Geoffrey Anderson, vice president of Sony Electronics' Advanced Wireless Technology Group. "Ultrawideband could really be a huge benefit to the consumer market."

But the same qualities that enable such an array of applications also make ultrawideband divisive. In February, the Federal Communications Commission gave limited approval to the technology, opening the door to its commercialization, if only a crack. The FCC process generated almost 1,000 public comments—many more than most proposals elicit. And while much of the feedback was supportive, cell phone makers and service providers, Global Positioning System companies, satellite radio firms, airlines, and a slew of civilian and military government agencies all objected to the FCC's plans to approve ultrawideband. Their beef: ultrawideband transmissions would interfere with the radio frequencies they rely on. These groups cited consequences ranging from the inconvenience of dropped cell phone calls to the frightening scenarios of foiled guidance systems preventing planes from landing in poor weather and wayward bombs that hit civilians. "The price of that interference is going to be very severe if a bomb is misdropped," says Badri Younes, assistant secretary of defense and director of the U.S. Defense Department's office of spectrum management.

For now, with few systems around for testing, discussions of ultrawideband's promise and peril are largely theoretical. Although the FCC and other agencies have done some testing of the technology, the trials have mostly been conducted using lab devices—whose ultrawideband signals may be stronger, or weaker, or otherwise very different from those that will be produced by real-world devices.

With the new regulatory backing, companies will finally bring the technology to market over the next few years, and the practical answers needed to resolve the technical and political uncertainties about ultrawideband's potential should emerge. Then we'll see whether ultrawideband will transform the wireless world—or bring it crashing down.

Ultrawideband Comes Through



An ultrawideband box could transmit different cable channels to TVs throughout a home. Although walls block some of the frequencies used, enough penetrate to reconstruct the signal.

PULSES OF POWER

Ultrawideband was born in the military labs of the 1960s. Looking for a way to let radar "see" through trees, researchers came up with the idea of using extremely short pulses of radio energy. Fundamental physics dictates that ultrashort pulses occupy a wide swath of the radio frequency spectrum; at least some of these frequencies, the theory went, were sure to penetrate leaves and branches.

Familiar wireless devices ranging from FM radios to cell phones to wireless computer networks using the increasingly common 802.11b standard all transmit continuous signals on narrow frequencies within the radio spectrum. Digital cell phones on the Sprint PCS network, for example, operate at around 1.9 gigahertz; 802.11b networks (and newer cordless phones) operate at 2.4 gigahertz. These transmissions occupy a thin slice of the spectrum and so generally do not interfere with other systems that depend on radio wave transmissions.

Ultrawideband radios, however, work in a fundamentally different way, emitting extremely short bursts of radio waves—just billionths or trillionths of a second long. Each pulse covers up to several gigahertz of radio spectrum. Information is transmitted by modulating the timing, amplitude, polarity or some other aspect of the pulses. An object's location can be inferred by methods like those used in traditional radar systems, such as "listening" for the echo of a directional signal and timing how long it takes to return, or triangulating on a target with multiple transceivers. The extremely short pulses used in ultrawideband make the position information highly accurate, down to the centimeter scale—unlike GPS, which is typically accurate only to tens of meters.

Sending information in pulses makes the radios much simpler, and therefore cheaper, to build than typical transmitters. That's because conventional narrowband radios require, among other design complexities, multiple analog components to tune the frequencies they emit. An ultrawideband transmitter, however, works like a tuning fork. Striking a tuning fork causes it to vibrate, sending out sound waves at a particular frequency. A semiconductor chip in an ultrawideband radio "hits" an antenna with carefully timed electrical pulses; the antenna responds by generating radio waves at

every frequency possible. "Ultrawideband systems are just brain-dead simpler to build," says Carl Howe, an analyst at Forrester Research in Cambridge, MA.

Simpler circuit designs and the pulsed nature of the transmissions also allow ultrawideband radios to transmit at much lower power than other wireless technologies. This gives ultrawideband an edge when it comes to battery-powered devices, since other high-bandwidth technologies require multiple power-consuming components *(see "How Ultrawideband Stacks Up," this page)*. And the wide swath of frequencies that ultrawideband transmissions occupy helps them travel through walls; even if one frequency is distorted or doesn't make it through, others still carry the signal *(see "Ultrawideband Comes Through," p. 73)*.

Another advantage of ultrawideband is its relative immunity to so-called multipath interference. When radio waves encounter obstacles, they bounce off them; echoes that arrive at the receiver out of phase with the original signal can cancel it out. A cordless-phone user walking away from the phone's base station in his or her home experiences this phenomenon as the fading of the caller's voice. But with ultrawideband's extremely short pulses, the original signal reaches the receiver in its entirety before the first echo arrives. Today's microchips are sophisticated enough to tell the difference between the two—or even to add them together to make the signal stronger. So ultrawideband can operate well in echo-prone places where conventional wireless systems suffer, such as living rooms or crowded cities.

HOME WITHOUT WIRES

The FCC's February decision allows the commercialization of ultrawideband on an unlicensed basis—the same arrangement under which technologies like cordless phones and wireless data networks such as Bluetooth and 802.11b operate. The good news here for companies deploying ultrawideband systems is that they will not have to pay for the spectrum their technology uses. The bad news is that to assuage licensed service providers (like cell phone companies) who fear that ultrawideband might interfere with their slices of the radio spectrum, the FCC put strict limits on the new technology. Consumer ultrawideband radios are permitted to transmit only very feeble signals, at one-thousandth the power that personal computers are allowed to radiate just by being on, and only in specific frequency ranges: below 960 megahertz, between 3.1 and 10.6 gigahertz, and between 22 and 29 gigahertz. Practically, this means that the new radios will be limited in either the distance they can transmit or the data rates they can achieve.

But even within those constraints, one of the technology's most promising applications might well have room to blossom. Ultrawideband could serve as a near ideal medium for short-range "personal-area networks" that connect electronic devices. This concept is already embodied in the communications standard known as Bluetooth. But ultrawideband radios will be like "Bluetooth on steroids," says Martin Rofheart, XtremeSpectrum's cofounder and CEO.

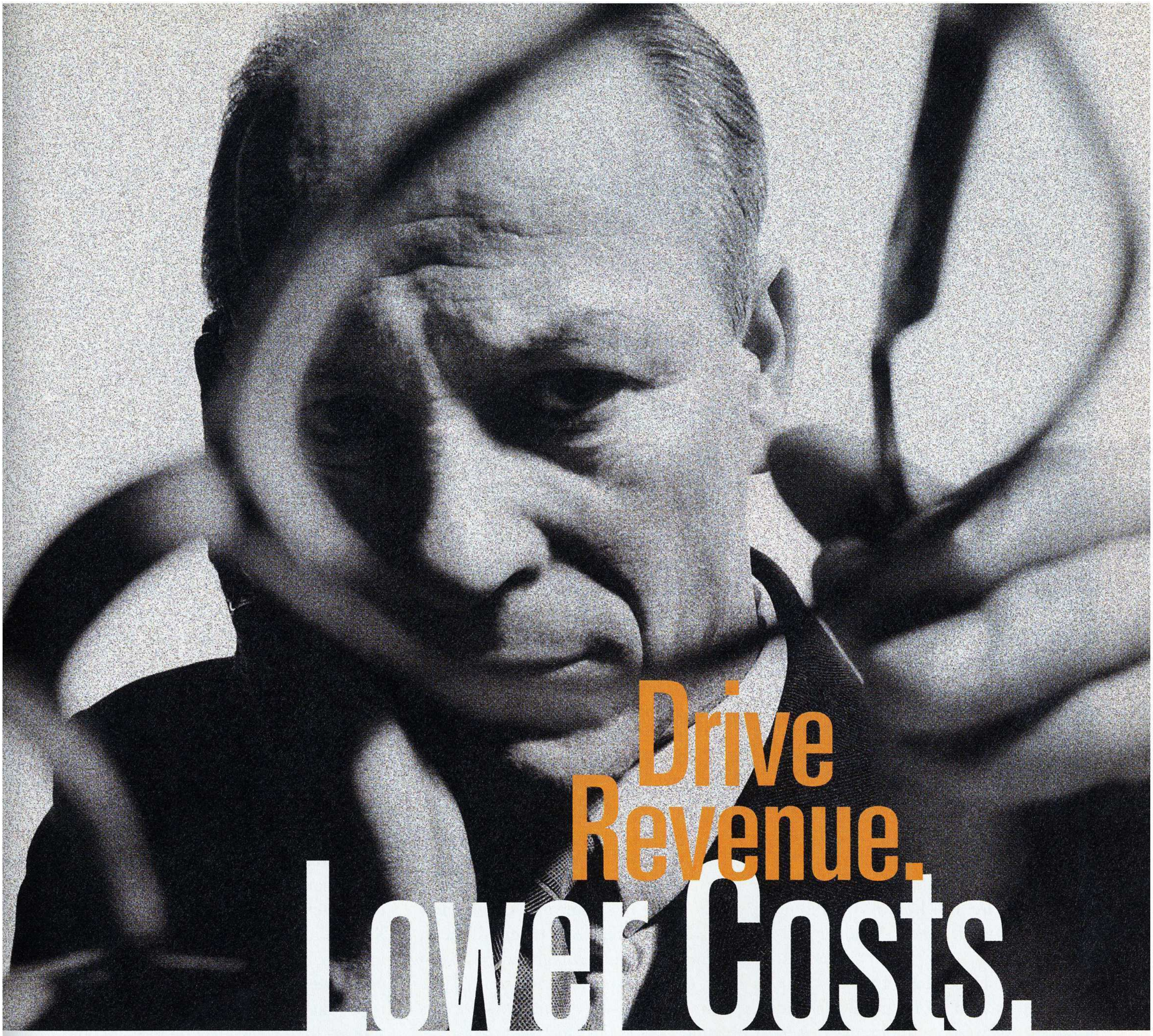
For one thing, ultrawideband will be a lot faster than its rival—capable initially of transmitting 100 megabits per second across a distance of 10 meters, or about 100 times Bluetooth's speed. That makes ultrawideband suitable for connecting devices like camcorders and TVs or computers and peripherals—applications requiring more bandwidth than Bluetooth can deliver. XtremeSpectrum, for example, has built a prototype that simultaneously sends DVD-quality audio and video across a room from player to TV. The system, cited as "best wireless technology of 2002" at the Wireless Systems Design conference in San Jose, CA, sends data from as many as four players to four television sets. Such a hookup could potentially distribute different cable television signals to multiple TVs in a home. That's an application that has lured AT&T into studying the technology as well. "There are a lot of benefits," says wireless researcher Saeed Ghassemzadeh of AT&T Labs-Research—not least of which would be the elimination of the cost of materials and labor to wire multiple access points around a house or apartment.

The same broadband-data capabilities could also make ultrawideband a wireless replacement for the cables that connect computers with peripherals like printers and scanners. Intel began an ultrawideband research project about two years ago and is considering the technology's potential to replace the newest version of the Universal Serial Bus (USB) standard, which transmits data at 480 megabits per second via cables. Both XtremeSpectrum and another ultrawideband company, Time Domain of Huntsville, AL, aim to reach data rates of 400 to 500 megabits per second within the next year. And Pulse-Link's Watkins says that by year's end his company hopes to be making prototypes that approach speeds of one gigabit per second for distances up to 10 meters—faster than Ethernet and other current wired con-

Ultrawideband tags could let robotic vacuum cleaners or lawn mowers do their household chores without ever hitting a sofa or a tree.

How Ultrawideband Stacks Up

TECHNOLOGY	RANGE (METERS)	DATA RATE (MEGABITS/SECOND)	POWER (MILLIWATTS)	BEST SUITED FOR	COMMERCIAL AVAILABILITY
Ultrawideband	10	100	200 (peak)	Short-range, high-speed data transfer (such as wireless video and audio)	2003 (estimated)
802.11a	50	30	1,000-2,000	High-speed wireless computer networks	Now
802.11b	100	6	500	Computer networking and Internet access	Now
Bluetooth	10	1	30	Connecting computing devices over short distances for text transfer	Now


Drive
Revenue.
Lower Costs.

nections. Within three to five years, Watkins adds, Pulse-Link will build devices that transmit data much farther—50 to 100 meters—and at speeds 10 to 50 times faster than today's 802.11a and 802.11b wireless networking technologies.

PINPOINT POSITIONING

But the technology's real strengths go beyond wireless data transfer. Walter Hirt, ultrawideband-project leader at IBM's research lab in Zürich, says ultrawideband is exciting because it offers the ability to combine data transmissions with location information in a way other wireless technologies cannot.

Three ultrawideband outfits, for example—Æther Wire and Location in Nicasio, CA, Israeli company Pulsicom and Multispectral Solutions—are developing systems of extremely high precision to track people and objects in real time. Small transceivers attached to merchandise would allow stores to accurately track, retrieve and catalogue inventory in warehouses and storerooms; the tracking systems would also monitor against theft. Multispectral Solutions has already built a system for the navy that it hopes to apply to retail shipping and warehousing problems. Hospitals, meanwhile, could use the technology to quickly run down equipment and people in emergencies.

Æther Wire also hopes to combine GPS receivers with ultrawideband for positioning systems. GPS, which works best outdoors, would locate an object to within a few meters; then a local ultrawideband infrastructure would pinpoint location to within a few centimeters—even indoors. In the short term, pager-sized versions of the technology could be used for public safety applications like tracking firefighters in a burning building; such devices could transmit temperature, oxygen levels and vital signs to the fire marshals outside. "In an emergency situation, you need to know where people are," says Æther Wire cofounder Robert Fleming. "When you have guys in buildings, you can't see where people are. Your own guy could be six inches away, across the next wall." Ultimately, the company envisions systems so cheap that parents could slap sticky ultrawideband tags on their kids to keep tabs on them in malls or theme parks.

Collision avoidance radars—like the one built by Fontana's Multispectral Solutions—are another ultrawideband strength. Initially built to sense the proximity of obstacles to unmanned aerial vehicles, such systems could serve as backup sensors in cars. DaimlerChrysler has already built a prototype car that couples an ultrawideband-based collision avoidance radar with controllers that gently engage the brakes if the vehicle appears to be heading for a crash. "It's extraordinary driving it, because as your foot is on the gas and you're backing up towards a pole, even though your foot is on the gas, the car comes to a gradual stop," says Tim McBride, who helped DaimlerChrysler push for FCC approval of ultrawideband as the company's vice president of Washington affairs. McBride says that, with the necessary approvals, cars incorporating the system could be on the road within the next few years.

Even a single ultrawideband radio, critics say, could interfere with airline safety systems—like those that help planes land in bad weather.

Ultrawideband companies hope to establish markets for both types of applications quickly. This year, both Time Domain and XtremeSpectrum released their first ultrawideband chips, which electronics makers like Sony (a Time Domain investor) could incorporate into consumer products like TVs, camcorders, computers and stereos. XtremeSpectrum's Rofheart expects to see ultrawideband radios in high-end consumer electronics (like plasma screen TVs) by late 2003. He says that the wireless links may start appearing in mass-market products a year later.

RUNNING INTERFERENCE

Despite ultrawideband's promise, attempts to deploy the technology face significant obstacles. The most immediate barrier is the FCC rules, which are designed to mitigate ultrawideband's potential to interfere with virtually every existing radio frequency service. "With the rules the commission enacted, you'll be lucky to get a signal across a room," says Dewayne Hendricks, founder of the Fremont, CA, wireless engineering firm the Dandin Group and a technical advisor to the FCC on new wireless technologies.

Ultrawideband's unique nature made the FCC's approval process especially contentious. The proposed short-range applications would use very low power pulses, which ordinarily would lessen their potential to cause interference. But ultrawideband signals overlay large parts of the radio spectrum. Although many proponents say these broadband pulses look like harmless "noise" to other radios, the signals could, in theory at least, disrupt a host of wireless applications—from TV to cell phones to GPS—that have paid big money for their slices of the spectrum. And if large numbers of ultrawideband transmitters come into use, the cumulative effects might inflict even greater interference. Many of the comments to the FCC on ultrawideband constitute a "yes it does, no it doesn't" back and forth on the interference question—even in the interpretation of data from technical studies. "As usual with studies," says Hendricks, "you can get credible scientists on both sides of the story."

Sprint PCS, for example, conducted tests indicating that ultrawideband signals could lead to more dropped calls and even lower the number of calls the network could handle, meaning more busy signals. Satellite radio companies Sirius and XM Radio are concerned about potential interference with their services. And tests performed by the National Telecommunications Information Administration showed that ultrawideband signals could make it more difficult for GPS receivers to lock onto satellite signals—and could also reduce their accuracy. That prospect would be especially troubling for the air traffic control system, which in coming years will rely increasingly on GPS.

The FCC's prohibition on ultrawideband emissions at certain frequencies was designed specifically to prevent potential interference with such systems. But those limitations are not enough, say some in the affected industries. Preliminary tests by NASA's Langley Research Center using ultrawideband emitters placed inside and outside United Airlines planes show that even at frequencies that the FCC is permitting, ultrawideband interference could compromise the instrument landing system pilots use to land in

Precision prototype: Æther Wire's pager-sized transceiver uses ultrawideband signals to track its carrier's location down to the centimeter.
PHOTOGRAPH BY ANNE HAMERSKY

bad weather. James Miller, program manager of flight operations technology at United, says that ultrawideband noise could additionally affect voice communications between air traffic controllers and pilots, the radars air traffic controllers use to track aircraft, and the collision avoidance system designed to prevent planes from crashing in midair. Airlines and the Federal Aviation Administration adamantly oppose permitting ultrawideband to operate in any frequency used by airlines; even a single ultrawideband radio could cause problems with these critical systems. "The question is not whether there's interference, the question is how much interference can flight crews tolerate," says Miller—and he says the airline industry's position is zero tolerance. "Any interference injected into the cockpit is a bad idea."

Many ultrawideband proponents contend that improper testing exaggerates the technology's interference effects. "A lot of the stuff put up for testing purposes with the FCC—you can't build efficient systems that way," says Pulse-Link's Watkins. Others suggest that the approval process became highly politicized. "Science wasn't really part of the debate anymore after a time—it became politics," says the Dandin Group's Hendricks.

Makers of ultrawideband systems hope that working commercial products will demonstrate that the radios do not cause interference. In fact, some devices under development—like Æther Wire's systems combining GPS and ultrawideband—would not work if ultrawideband caused as much interference as critics say it will. Indeed, says XtremeSpectrum's Rofheart, avoidance of interference-caused "radio fratricide" is key to future applications that would mingle cell phone, GPS and ultrawideband radios.

Adamant opponent: James Miller of United Airlines says ultrawideband signals could cause dangerous interference in radio bands used for airline safety.
PHOTOGRAPH BY CHRIS LAKE

Ultrawideband proponents also worry about the trouble other radio technologies might cause them. Because conventional narrowband systems, like cordless phones, operate at much higher power than ultrawideband radios, their transmissions could overwhelm nearby ultrawideband devices. Designing ultrawideband receivers so that they block certain frequencies could solve the problem—but also make the radios more complex and costly.

SETTING THE STANDARD

In the long run, the interest of major players like Intel, IBM and Sony could well give ultrawideband the push it needs to become as ubiquitous as cell phones. But first, its adherents will have to resolve the present multitude of proprietary approaches into a single standard, like the wireless networking standards 802.11a and 802.11b. Without standardization, one brand of DVD player, for instance, might not be able to send ultrawideband data to a TV from a different maker. Rofheart predicts that by early next year, the Institute of Electrical and Electronics Engineers will endorse an "802" standard for personal-area networks that incorporates ultrawideband. That, he says, will go a long way toward securing a market for the technology.

European and Asian adoption of regulations similar to the FCC's could help the technology even more, by creating a worldwide regulatory framework that would finally allow wireless devices to work in any country. "Because we're not dealing with frequencies that have been assigned differently in different countries, we have the first possibility of creating a global interoperable standard," says Pulse-Link president Watkins. IBM's Hirt says that the European Conference of Postal and Telecommunications Administrations plans to formulate an ultrawideband policy by the end of 2003 and seems to be leaning toward mirroring the FCC regulations.

Ultrawideband opens the possibility for a common global standard that would finally allow wireless devices to work anywhere in the world.

The action that would most benefit ultrawideband would be for the FCC to allow transmissions with higher power and at lower frequencies. And indeed, the commission is scheduled to revisit its ultrawideband regulations within six to 12 months and has signaled an intent to relax its restrictions. That could result in even simpler-to-design systems that might, among other things, solve the expensive "last-mile" problem by transmitting data from high-speed fiber-optic Internet networks to homes. Such hookups would provide connections tens of times faster than those offered by telephone and cable companies.

Some skeptics think it will be years before ultrawideband takes off at all. Kevin Kahn, who heads Intel's efforts, believes a practical data transmission product is at least three to five years away. Ken Dulaney, a mobile-computing analyst at the consulting firm Gartner, is even more conservative, estimating that it may take seven years for the technology to gain the kind of consumer acceptance 802.11b networks enjoy—if it ever does. Ultrawideband, he says, is "really an engineering experiment that now at least has a legal backing."

But whether ultrawideband matures in two to three years or unfolds over the course of a decade, Multispectral Solutions president Fontana is confident that the technology will eventually succeed. "When the FCC opens up over nine gigahertz of spectrum, even if these companies don't survive—including us—there will be other companies that will take advantage of that," he says. And when they do, the world may be a giant step closer to living like the Jetsons. TR

An Ultrawideband Who's Who

COMPANY	FUNDING	APPLICATIONS	STATUS
Time Domain (Huntsville, AL)	Investors include Sony and Siemens	Data transfer; precision location; radar	Radar products on the market; first communications chips to be released this year
Multispectral Solutions (Germantown, MD)	Military contracts (primarily DARPA, air force and navy)	Voice communications; data transfer; precision location; radar	Military systems in use; civilian applications under development
XtremeSpectrum (Vienna, VA)	Investors include Cisco Systems, Motorola and Texas Instruments	Multimedia data transfer	First chips released this year
Æther Wire and Location (Nicasio, CA)	Military contracts (primarily DARPA)	Precision location	Prototype demonstrated
Pulse-Link (San Diego, CA)	Undisclosed	Data transfer; precision location	Chips scheduled for release 2003
Pulsicom (Or Yehuda, Israel)	Investors include Intel Capital	Precision location	Chips scheduled for release late 2003
Intel (Santa Clara, CA)	Internal	Data transfer	Prototype demonstrated
IBM Research (Zürich, Switzerland)	Internal	Networking	Long-range R&D
AT&T (New York, NY)	Internal	Multimedia data transfer	Long-range R&D

Moo times two: Jose Cibelli with Charlie (left) and George, two of the steers he has helped clone.

DEMO

cloning COWS

Wish you had a whole herd with the same meat-producing prowess as your blue-ribbon steer? No problem—just clone him. Jose Cibelli can help.

Most scientists spend their graduate-school years generating reams of data that wind up in the pages of a scientific journal or collecting dust in the university library. Jose Cibelli's PhD project wound up swatting at flies in a grassy pasture near the University of Massachusetts Amherst, where the reproductive researcher earned his degree. Shown here flanking Cibelli, Charlie and George were among the first cattle ever cloned when they were born in January 1998. These days Cibelli and his colleagues at Worcester, MA-based Cyagra are turning the once experimental technique used to produce the twin Holsteins into a commercial enterprise. In the space of a year and for a fee of $19,000, Cyagra will transform a tiny skin sample from a prized animal into a living, breathing clone of the creature. Though Cyagra—a spinoff of biotech company Advanced Cell Technology—isn't saying publicly how many customers it's had so far, Cibelli says it has the ability to clone an animal in a day. During a visit this summer, *Technology Review* senior editor Rebecca Zacks got a chance to watch Cibelli do just that, and to meet George and Charlie.

PHOTOGRAPHS BY KATHLEEN DOOHER

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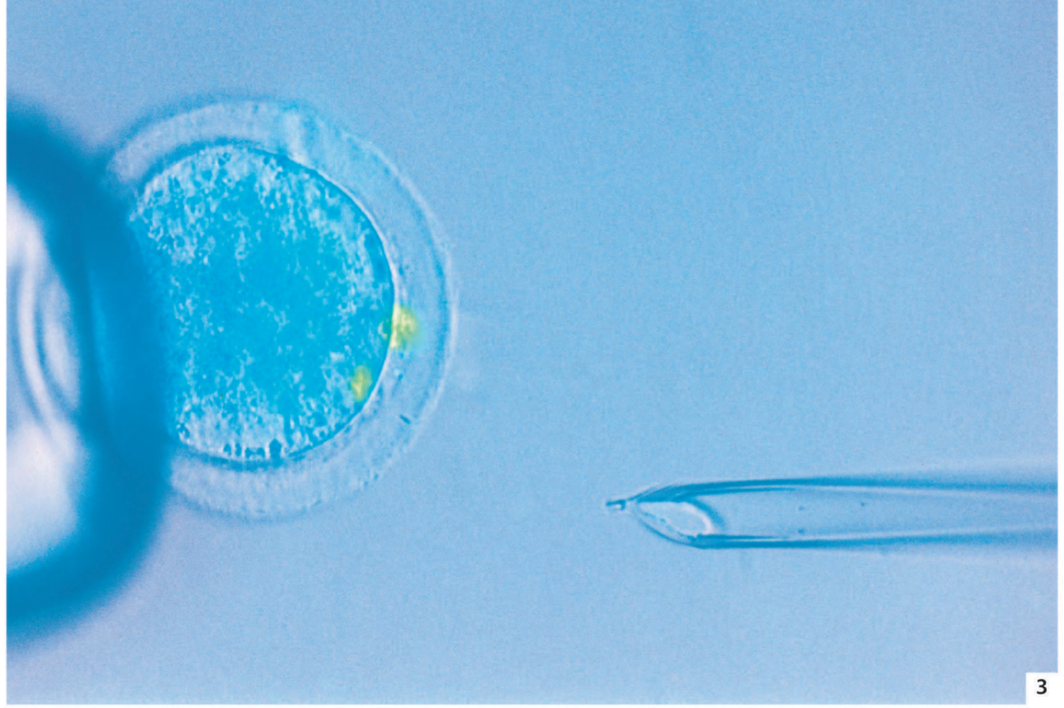

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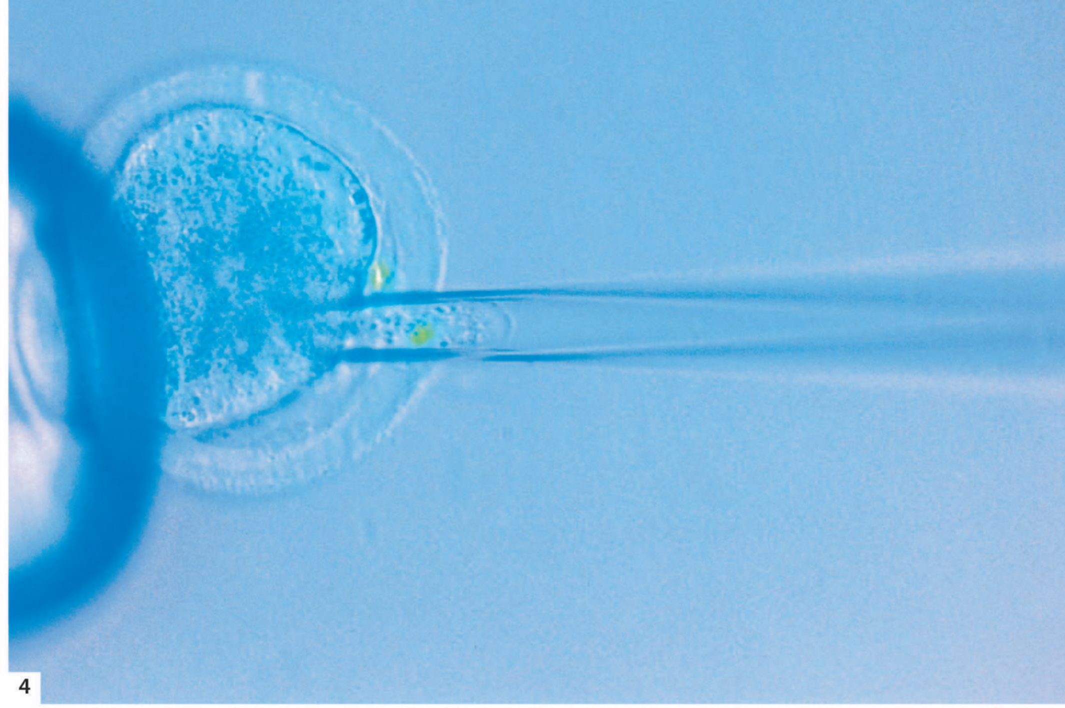

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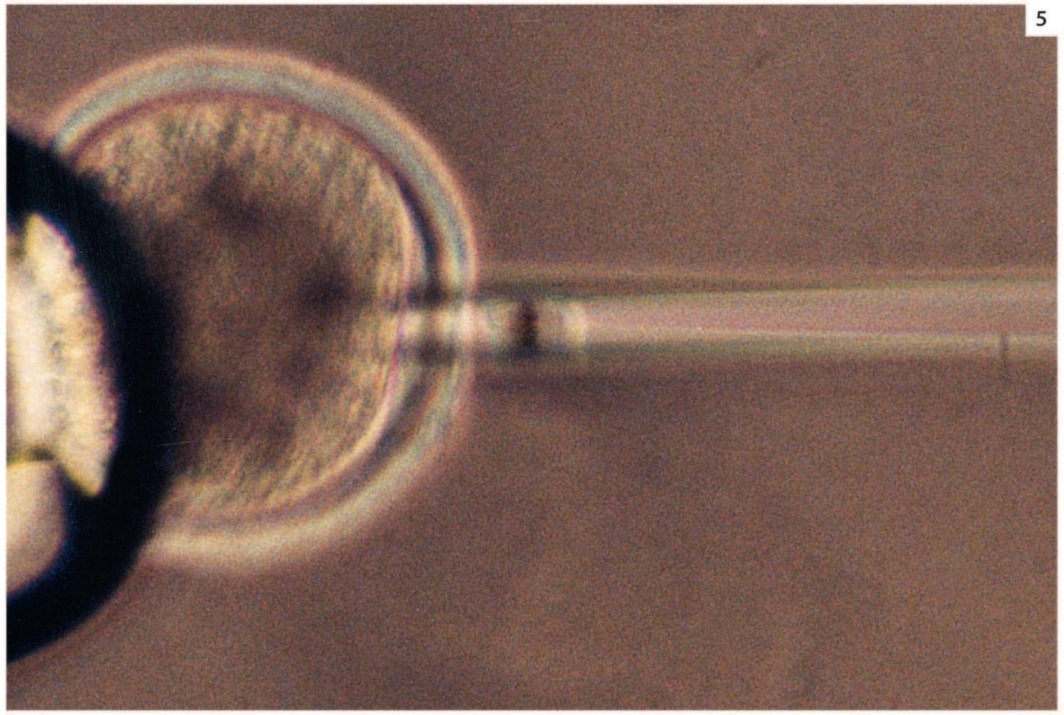

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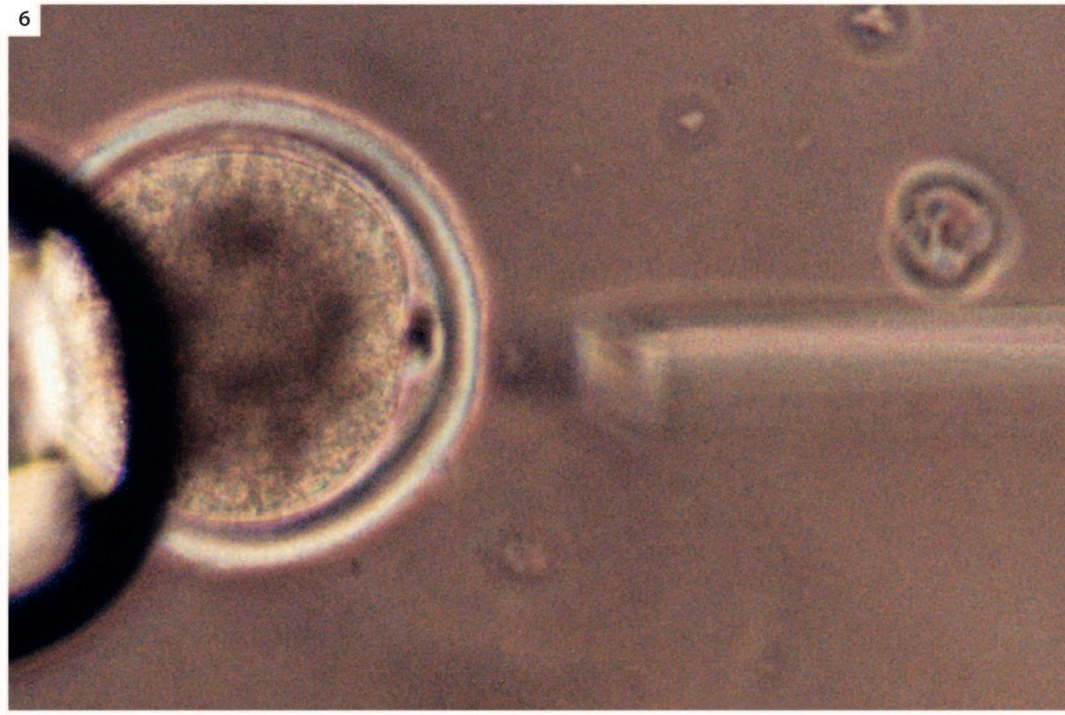

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1-2 TOOLS OF THE TRADE. Cibelli uses specialized glass needles to manipulate the cow eggs and skin cells that will eventually become clones. "You need to make your own tools," he says. "You can't buy them." Using a glass-pulling machine, he shapes a thin glass tube into a hollow needle; with a second machine *(top left),* he trims the needle's point to make an opening the right size for holding an egg. He repeats the process, crafting a needle with a finer, more angled point for piercing the tough envelope surrounding the egg. He cleans the needles and mounts them on robotic arms attached to a microscope *(bottom left)*. Fingertip controllers will allow him to move the needles and draw fluids in and out of them.

3-4 OUT WITH THE OLD. Through the microscope, Cibelli surveys a collection of eggs harvested two days before from the ovaries of cows in a Nebraska slaughterhouse. He grabs hold of one by drawing fluid into the wider needle to suck the egg against its tip. What he wants to do is remove the egg's nucleus—home to its chromosomes—without damaging the egg. He taps a pedal to turn on an ultraviolet light that, thanks to a special dye, reveals the nucleus as a small glowing spot, just below and to the left of a brighter structure called the polar body. Cibelli takes aim with the narrower needle and pierces the thick and somewhat rigid envelope, called the zona pellucida, that protects the egg. He stops short of penetrating the thin stretchy cell membrane of the egg itself, though. "If you pierce the egg, you kill the egg," he says. Instead, he applies gentle suction to the side of the egg, the needle acting much like a vacuum cleaner hose pressed against a balloon filled with Jell-O. By carefully controlling the suction, Cibelli coaxes part of the egg, including the nucleus, to flow into the tip of the needle. He draws the needle back very slowly. "Sometimes you get what we call the mozzarella effect," he says, where a thin string of cell membrane forms between the needle and the egg—and eventually causes the egg to rupture. This time he's lucky, though: the cell membrane pinches itself off cleanly. "Now there's no more DNA inside the egg," he says.

5-6 IN WITH THE NEW. From an incubator behind him, Cibelli takes a petri dish full of cultured skin cells. These are "the cells that will be the future animal," he explains. They were grown from a six-millimeter-wide biopsy taken two weeks earlier from the ear of the cow he's trying to clone. Though tiny compared to the 120-micrometer-wide egg, each cell holds a complete set of chromosomes—all the genetic information necessary to make a new cow. Cibelli draws one skin cell into the tip of the narrower needle and once again pierces just the zona pellucida. Applying a slight pressure to the needle, he squirts the skin cell out so that it's wedged tightly between the zona pellucida and the egg's cell membrane.

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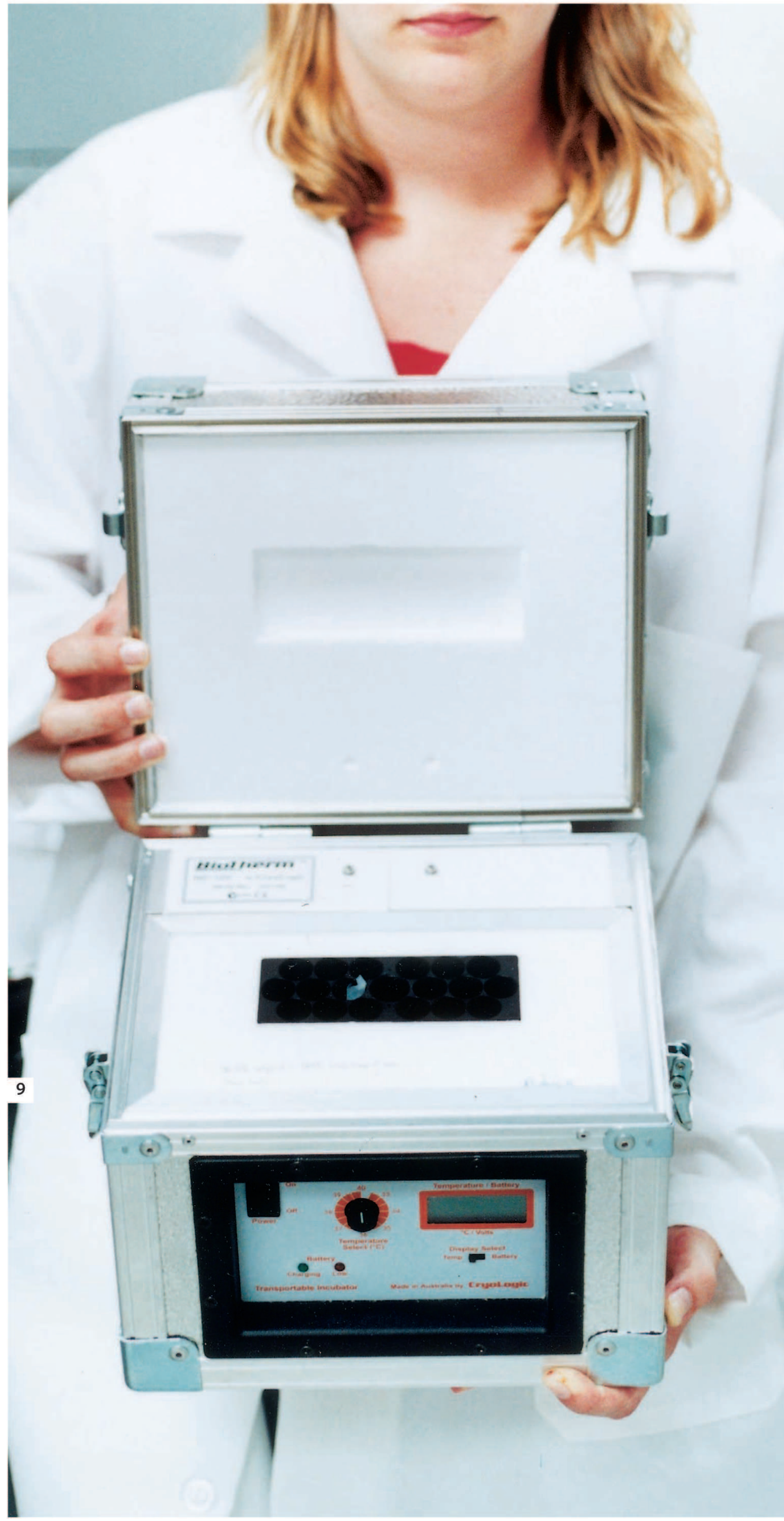

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7 SPARKED TO LIFE. Once Cibelli has prepared 10 eggs in this same manner, he transfers them to another petri dish outfitted with two long electrodes running horizontally across a plastic platform. Working freehand with another glass needle, this one with a tip that's sealed shut, he lines the eggs up Rockette-style on the platform between the electrodes. As he attaches alligator clips to the electrodes, he explains that the clear fluid in the petri dish is a sugar-based solution, which will protect the eggs from electrical damage. "If you have ions like sodium chloride, it will basically fry the eggs," he says. Instead, what Cibelli wants to do is zap them with just enough electricity to cause the egg and the skin cell to fuse together, thereby delivering the skin cell's nucleus into the egg. All it takes is a microseconds-long pulse (the exact length is yet another trade secret, Cibelli says with a smile) of 100 to 200 volts. Cibelli flips a switch and, in an instant, creates clones.

8 DOUBLE CHECK. The fusion procedure isn't always a perfect one, though, so Cibelli checks once more under the microscope to make sure that each egg has fused with a donor skin cell. "The electricity also triggers activation of the egg," he says, referring to the cascade of events—normally initiated by a sperm—that kicks off the rapid cell divisions that will ultimately produce a new creature. Cibelli slips the petri dish of activated eggs into an incubator and shuts the door. "By tomorrow morning," he says, "they will be two-celled embryos."

9 BACK TO THE FARM. After a week in the incubator, Cibelli says, the new clone embryos will be ready to ship to Cyagra's farm in Pennsylvania. He introduces Cyagra researcher Nancy Kieser, who holds up the battery-powered shipping container that will keep the embryos warm for the journey. In Pennsylvania, veterinarians will implant the embryos in the uteri of surrogate mothers, and after nine months, the next generation of cloned cattle will be born.

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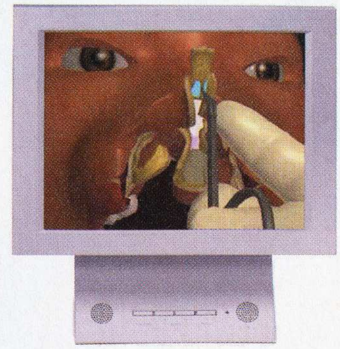

Our new virtual surgery software helps produce better cleft surgeons in a fraction of the time it used to take.

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Computer Associates™

OF ONCOMICE AND MEN

Most of the industrialized world is already busily patenting and manufacturing genetically altered organisms. Canadians, much to their credit, want to think things over. A case before Canada's Supreme Court concerning the patenting of lab-produced mice strains has focused national attention on the legal and social implications of genetic technologies. The Canadians are conducting this debate with the kind of verve and attention that Americans generally reserve for hot-button issues like the pledge of allegiance or gay marriage.

The stakes are high. Canada has the world's second-largest biotechnology industry after the United States'; roughly 400 Canadian biotech companies will do a projected $5 billion (Canadian) worth of business this year, according to BioteCanada, a Canadian biotech industry group. Considering that the U.S. Patent Office has wholeheartedly allowed the patenting of animal species and that Europe is slowly moving in the same direction, the pressure for Canada to follow suit is immense. If Canada adopts restrictive gene technology policies or delays a decision too long, multinational companies might well flee. Yet despite that threat, Canada is taking its time to deliberate on the policy ramifications of transgenic technology.

Canada's caution is wise because tough policy issues, tightly linked to today's patent case, lie ahead. Human cloning is at the doorstep. A host of new breakthroughs, like those in human stem cell research, promise treatments that raise profound ethical questions. Should we allow human beings to be cloned under any circumstances? Should we allow human germline treatments—manipulating genes in sperm and egg cells—to try to remove genetic diseases? These questions are closely tied to intellectual-property policy because patents help drive research. For instance, should companies that genetically alter the germline of an animal species be allowed to patent that species? That, in fact, was the question that sparked Canada's current debate.

Call it the oncomouse that roared. It all started back in 1982 when geneticists Phil Leder and Timothy Stewart at Harvard University inserted cancer-causing genes, or oncogenes, into a mouse. The resulting "oncomouse" and its offspring were useful because they offered a living model in which researchers could study the onset of cancer and test the efficacy of treatments. In the United States, Leder, Stewart and Harvard handily won a patent on transgenic mammals as a research tool in 1988 (more on that in a moment). In Canada, however, the legal fate of transgenic mice has been considerably more twisted.

First, in 1985, Canada's patent office refused to grant a patent for the oncomouse, saying it had no specific authority to grant ownership rights over a species of mammal. In 1998, a Canadian federal court sided with the patent office, but two years later, Harvard scored a victory in Canada's appellate court. The new decision offered the opposite argument: that the oncomouse patent must be granted because nothing in Canada's 1869 Patent Act specifically prohibits it. The Canadian patent office appealed to the Supreme Court of Canada. Insiders say a verdict could come as early as this fall.

In the meantime, the public has been engaged. The nation's environmental and biotech-industry groups were invited to submit their opinions and eagerly did so. Lawmakers proposed a sweeping package of legislation on everything from patenting higher species to human cloning and surrogate motherhood. (For more, see the Web site of Canada's ministry of health—www.hc-sc.gc.ca—and search for "reproductive and genetic technology.") When *TR* went to press no legislation had yet passed. But ultimately, the whirl of public interest surrounding the case will surely result in new policies that reflect citizens' concerns. Which is, I believe, as it should be.

Compare that story to the situation in the United States. In 1988, when the oncomouse received its first U.S. patent, the U.S. Supreme Court had long since flung open the door to such a claim. In a 1980 case called *Diamond v. Chakrabarty*, the high court validated (in a five-four decision) a patent on genetically engineered bacteria designed to fight oil slicks by breaking down crude oil. A 1987 case known as *Ex Parte Allen* extended the principle to include nonhuman multicellular organisms. It was just a matter of time before the Court would sanction the idea that a species of mouse with a slight genetic alteration could be considered a patentable invention.

Canadian lawmakers and citizens are actively engaged in shaping policy on patenting genetically engineered animals. Americans abdicate their civic duty by leaving such matters to judges.

That U.S. policy on something with such far-reaching implications is best explained by a recitation of obscure legal precedents makes a larger point: Americans are too content to leave vital policy matters to the courts. In the case of patenting, this is not just a mistake that will return to haunt us but an abdication of our civic duty as citizens in a democracy. Justice William Brennan of the U.S. Supreme Court had it right in his 1980 dissent on the original bacteria case when he wrote that lawmakers, not judges, are the ones who should broaden or narrow the reach of patent laws, especially when the subject of a patent "uniquely implicates matters of public concern." Before disputes over transgenic human patenting reach the U.S. courts, maybe we'll learn something from the engaged debate of our northern neighbors. TR

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VISUALIZE

HOW TECHNOLOGY WORKS

By Tracy Staedter | Illustration by John MacNeill

TRIPLE-JUNCTION SOLAR CELLS

Three semiconducting layers optimize solar power efficiency

Sunshine is free; turning sunlight into electricity is not. Photovoltaic solar cells are expensive to manufacture and not nearly as efficient as technologies that rely on fossil fuels. Most photovoltaics convert only about five to 20 percent of the sunlight that strikes them into electricity. But triple-junction solar cells—used mainly on satellites—are making their way to earth and proving twice as efficient as many other terrestrial photovoltaics.

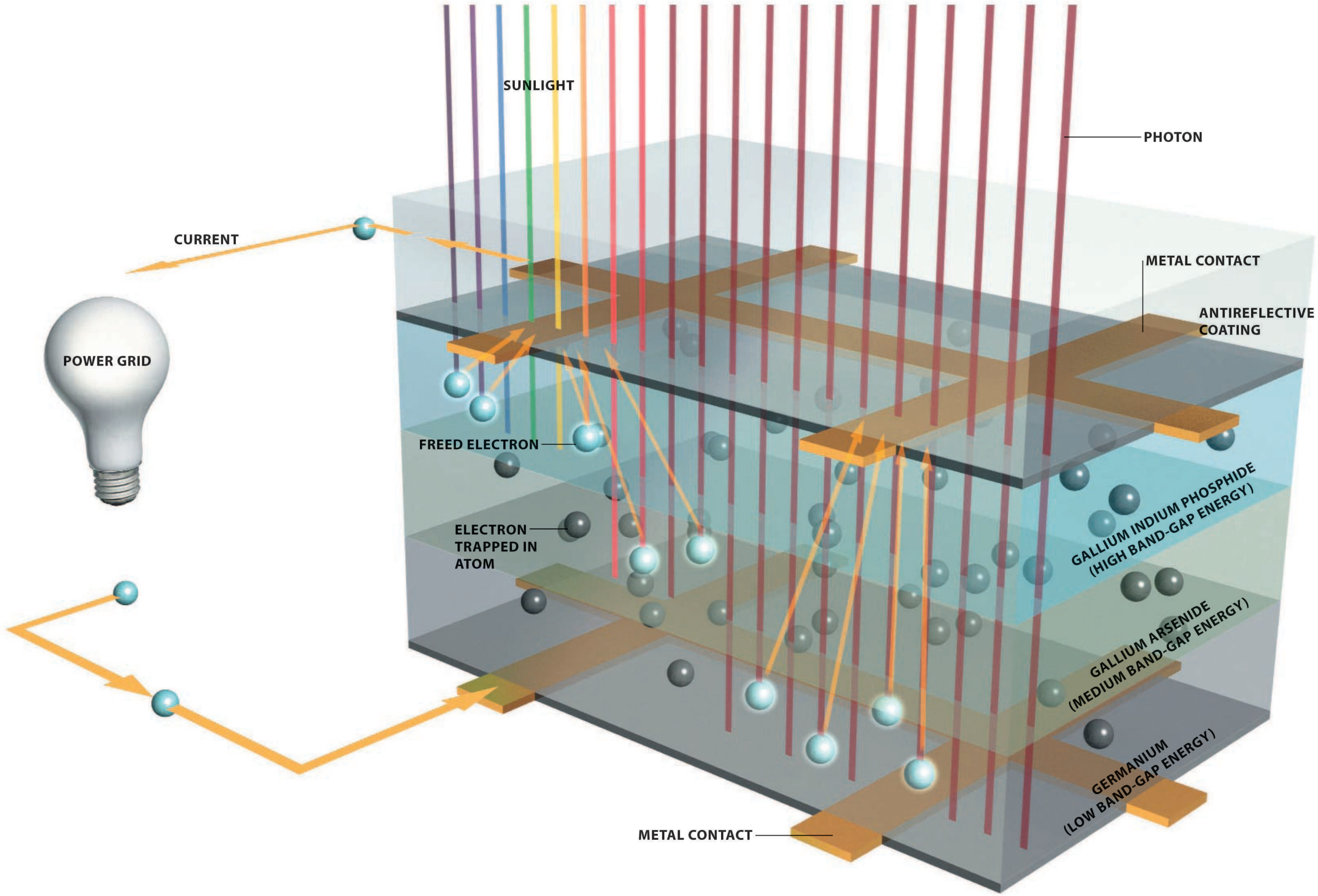
A triple-junction solar cell is made of three semiconducting layers sandwiched between a grid of metal contacts and capped off with an antireflective coating. The materials in the three semiconducting layers absorb photons from particular swaths of the solar spectrum, ranging from the ultraviolet to the infrared. In the most efficient cells available, the top layer is composed of gallium indium phosphide, which captures photons from the ultraviolet, violet, blue, green, yellow and orange part of the spectrum. The middle layer is made of gallium arsenide, which mostly absorbs red photons. The bottom layer is composed of germanium and reacts with low-energy infrared photons. Once the photons are absorbed by their respective layers, they knock electrons loose from their atomic bonds. The freed electrons flow through the semiconductors, creating a current that is tapped by metal contacts and ultimately used to generate power.

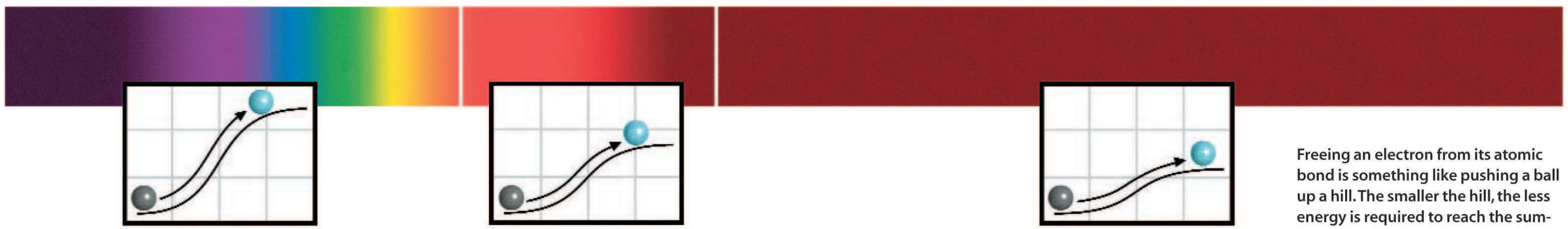
COURTESY OF SPECTROLAB

The arrangement and chemical composition of the three layers is key to optimizing the cell's performance. Each semiconductor material is defined by its so-called band gap energy—the specific amount of energy required to free an electron so that it will carry current. Energy lower than that will not free an electron, and higher energy is wasted on heating the device instead of generating more electricity. Arraying the layers so that sunlight strikes the highest-band-gap material first, then passes through layers with successively lower band gaps, extracts the maximum possible electrical energy.

Recently, Sylmar, CA-based Spectrolab, together with the U.S. Department of Energy's National Renewable Energy Laboratory in Golden, CO, produced the most efficient triple-junction photovoltaic cells yet. The Spectrolab system, which includes a large mirror to concentrate light onto a cell *(see photo)*, converts 34 percent of sunlight into electrical power. This fall, Arizona Public Service—the state's largest electrical utility—will add these and other photovoltaic cells to its power-generating arsenal. It hopes to have 1,000 kilowatts of solar energy feeding the grid by 2012. It's a small fraction of the utility's total generating capacity, but a big step in the right direction. Arizona is the only state in the union mandating the contribution of solar energy. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize





GALLIUM INDIUM PHOSPHIDE
Only photons in the ultraviolet to orange part of the spectrum have enough energy to free electrons in this layer.

GALLIUM ARSENIDE
Red photons have the right amount of energy to free electrons in this layer.

GERMANIUM
Even photons from the infrared part of the spectrum can free electrons in this layer.

Freeing an electron from its atomic bond is something like pushing a ball up a hill. The smaller the hill, the less energy is required to reach the summit. In triple-junction solar cells, each of the three semiconducting layers requires a different level of energy to knock its electrons into a state where they can carry a current.

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PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

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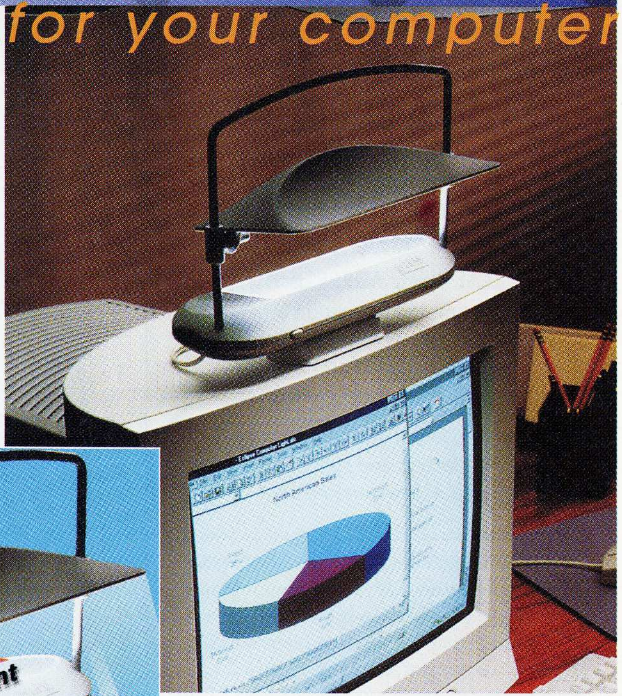
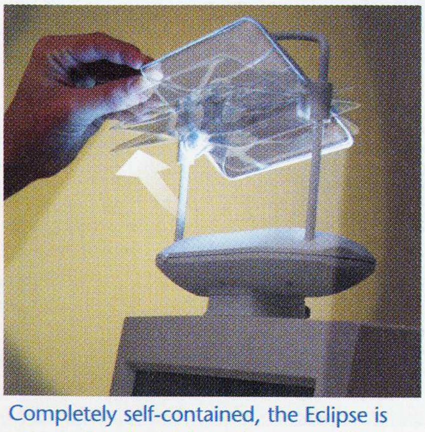
The ergonomically-designed Eclipse Computer Light helps reduce monitor glare and alleviate one of the causes of Computer Vision Syndrome.

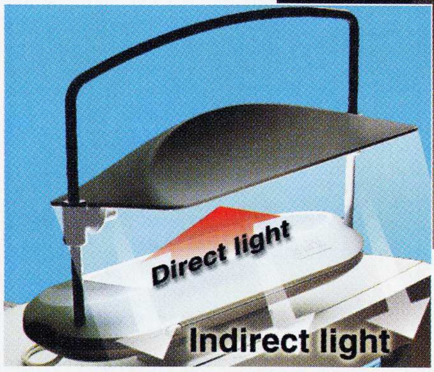


Did you know that more than two-thirds of U.S. employees are online at work and more than half of all U.S. households have computers? The average computer user spends 950 hours at a computer each year at work and approximately 300 hours in front of a computer at home, equivalent to more than 50 full days each year. Out of these people, the National Institute of Occupational Health and Safety finds that 91 percent suffer from eyestrain. The American Optometric Association uses Computer Vision Syndrome, or CVS, as the common term for eye and vision strain experienced after prolonged computer use. The Eclipse Computer Light can help alleviate these symptoms by reducing monitor glare.

The painful truth about CVS. Computer Vision Syndrome (CVS) is the complex of eye and vision problems related to near work which are experienced during or related to computer use. CVS is characterized by visual symptoms which result from interaction with a computer display or its environment. In most cases, symptoms occur because the visual demands of the task exceed the visual abilities of the individual to comfortably perform the task.* A study conducted by the Indian Institute of Technology found that computer work is visually demanding, with the eye shifting and focusing between the screen, document, and keyboard 25,000 times a day. The eye has to accommodate, converge, and adapt to these tasks under varying light of the video display. Two types of glare, direct and reflective, contribute to this problem. Direct glare makes light bounce off the screen directly into your eyes, while reflective glare (ambient glare) bounces needless illumination from behind or above you onto your monitor, and then into your eyes. What is needed is an indirect light source. Such illumination can help minimize eyestrain in your workplace.



Completely self-contained, the Eclipse is extremely adjustable and comes with a 10,000-hour snap-in fluorescent bulb.



The indirect lighting of Eclipse Computer Light results in an optimal, more "ergonomically-correct" workplace.

The ergonomic answer to eyestrain. The Eclipse Computer Light is an "ergonomically-designed" indirect light source that provides the proper amount of light for the desk area, without producing any monitor glare. It reduces desktop clutter because it sits on top of your computer, and with its futuristic design is simple and slick, making the light an integral part of a computer monitor. Completely self-contained, and fully assembled, the Eclipse is extremely adjustable and comes with a 10,000-hour snap-in fluorescent bulb. This energy-efficient bulb lasts between four to five years and generates less heat. Simply attach to your computer with double-sided, self-adhesive tape. Make your headaches and red, tired, blurry eyes a thing of the past when working at your computer with this stylish lamp.

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—Craig L.

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*American Optometric Association. Guide to the clinical aspects of computer vision syndrome. St. Louis: American Optometric Association, 1995:1.

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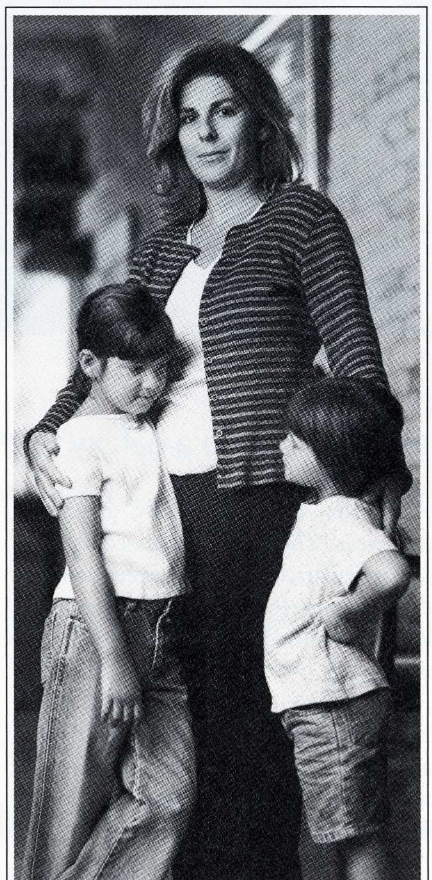
Reading is a great way to escape. It helped this family get out of the projects.



To families living in poverty, it sometimes seems there's no way out. And for many of them, poor literacy skills are the source of their own captivity. Today, one in every five people in America would have difficulty understanding these very words. A parent who can't read a job application can't earn a living. A child who fails in school doesn't earn a diploma. Entire generations become trapped in a bleak pattern of underachievement and need. Their only escape is through the classroom door. 📖 The National Center for Family Literacy is working to help break the cycle of intergenerational poverty by teaching parents and their children the skills necessary for success. Family members learn to read and write well, to maintain good study habits, to hold a steady job. They learn how to manage a household budget and to plan for the future. We hold out a hand and they learn to pull themselves up. 📖 We need a hand as well. You can volunteer to participate in a family literacy program. You can offer someone a job. Or you can simply write out a check. Whatever choice you make, you can be the reason one more family succeeds and poverty fails. 📖 Please call the Family Literacy InfoLine at 1-877-FAMLIT-1 or visit www.famlit.org.

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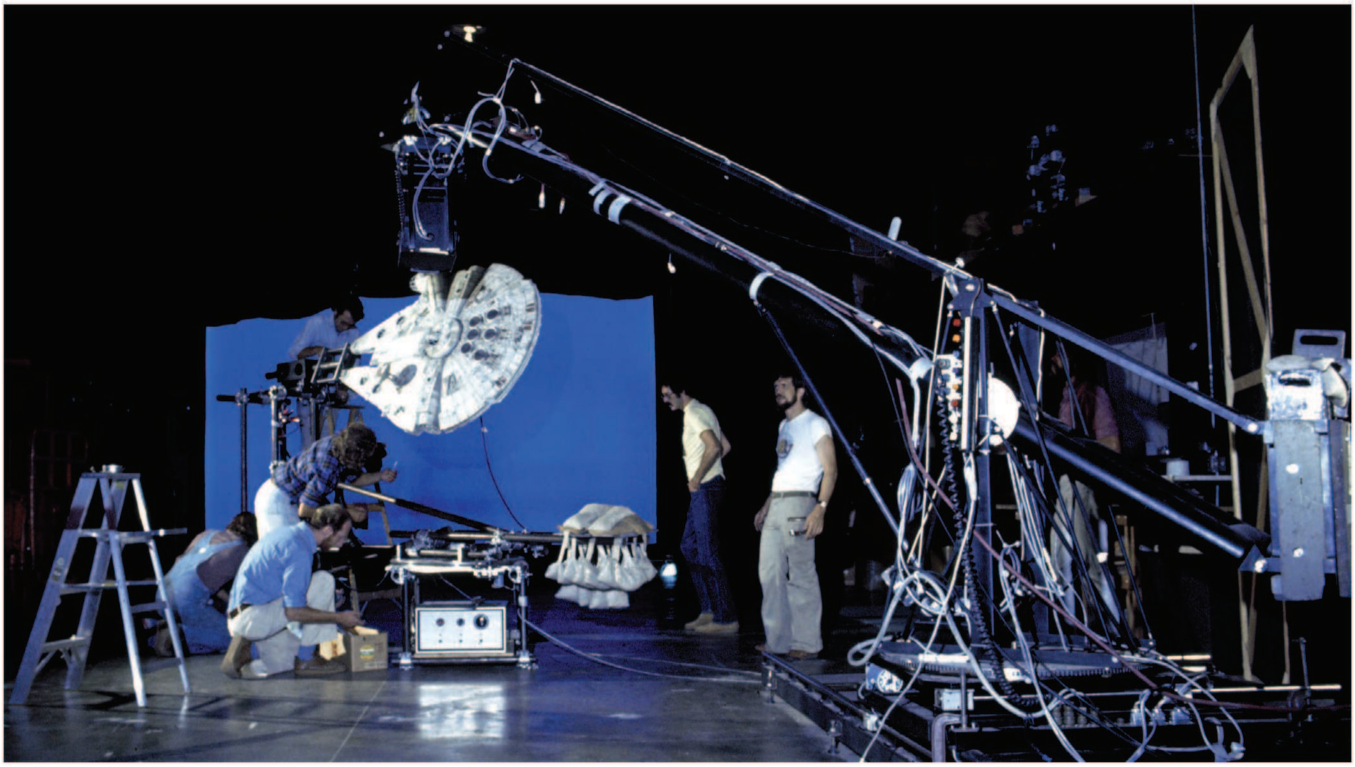

BLUE SCREEN ON THE SILVER SCREEN

The special-effects innovation that takes you to a galaxy far, far away

Look, up on the movie screen. Is it a bird, or a plane? If it's flying through the air or through outer space, the scene was likely created using a bit of movie trickery known as the blue-screen process. This special-effects technique allows a filmmaker to place objects and actors in difficult-to-film situations with ease. It has been steadily refined over the years and is now ubiquitous in big-budget juggernauts. The 2002 film *Star Wars: Episode II—Attack of the Clones*, for example, uses a version of the blue-screen process in nearly every shot. But the basic concepts behind this mainstay of the movie industry go back to the 1920s.

The process begins with the separate filming of the foreground and background of a shot. The objects in the foreground—miniature model alien spaceships, perhaps—are filmed in front of a special blue (or, occasionally, green or red) screen. The film is processed so that the particular color of the screen is rendered transparent on the film stock. A separately filmed background—say, an expanse of outer space—can then be inserted where the image of the blue screen once was. Finally, foreground and background are seamlessly combined, resulting in a shot that defies reality—alien ships flying through outer space.

In the 1920s, camera technician C. Dodge Dunning created a primitive blue-screen process, which he used in the pioneering 1933 film *King Kong*. But it was cumbersome, requiring special cameras and colored lighting, and it only worked with black-and-white film. It wasn't until the 1950s, when color had become the norm, that special-effects technician Petro Vlahos created a blue-screen process compatible with color film and conventional cameras. Vlahos's technique was employed in 1959's *Ben-Hur* and many other movies. But it wasn't until the release of the 1977 special-effects extravaganza *Star Wars (above)*, which made extensive use of blue-screen shots, that the technique took off. Before long, nearly every blockbuster was using blue screens. Vlahos won many accolades for his innovations, including a special 1993 award from the Academy of Motion Picture Arts and Sciences, given annually to "an individual…whose technological contributions have brought credit to the industry."

Blue-screen effects are now typically created with special software. Vlahos founded Chatsworth, CA-based Ultimatte, which manufactured the blue-screen software used on 2001's *The Lord of the Rings: The Fellowship of the Ring*. Like *Ben-Hur*, the film won an Oscar for its visual effects. TR

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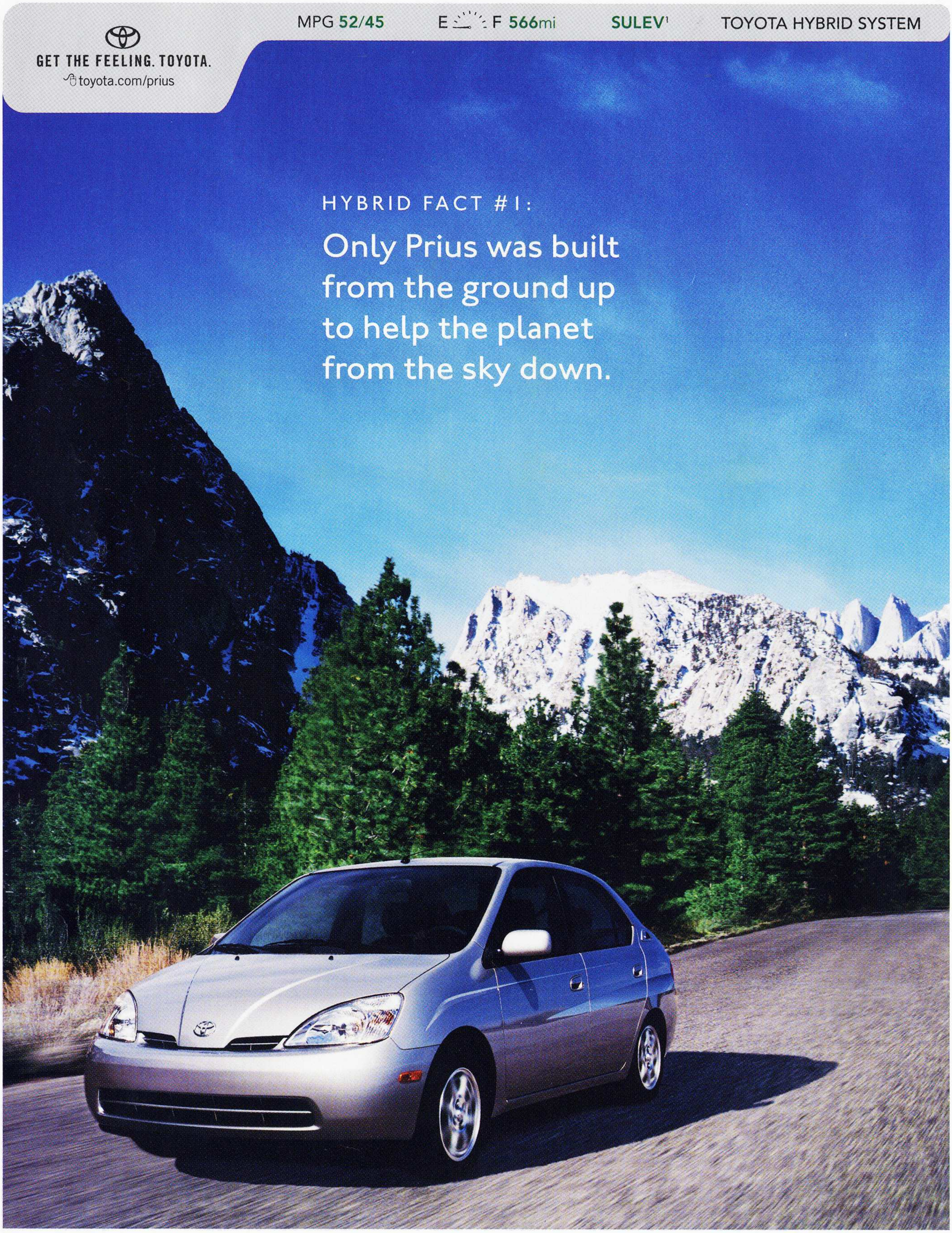

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